

THE
P H Y S I O L O G Y
OF THE
SENSES, VOICE, AND MUSCULAR MOTION,
WITH THE
MENTAL FACULTIES.

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OF THE
SENSES, VOICE, AND MUSCULAR MOTION,
WITH THE
MENTAL FACULTIES.

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TRANSLATED FROM THE GERMAN.

WITH NOTES,

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BOOK THE FOURTH.

Of Motion ; of Voice and Speech.

SECTION I.

Of the Organs, Phenomena, and Causes of Motion in Animals.

CHAPTER I.

OF THE DIFFERENT KINDS OF MOTION AND MOTOR ORGANS.

THE vital motions of the solid parts of animals present two principal kinds, differing in the organs of their production, in their phenomena, and in their causes: they are, the motion from contraction of fibres, and the oscillatory motion of cilia with free extremities, in which no other organic apparatus of motion can be distinctly demonstrated. The first kind of motion is produced by the shortening of fibres, which either have a longitudinal direction and are fixed at both extremities, or form circular bands; the contraction or shortening of the fibres bringing the fixed parts nearer to each other. This kind of motion is generally effected by means of muscular fibres; in some few instances it is produced by fibres which differ from the muscular in structure and chemical properties. The second kind of motion consists in the vibration, in a determinate direction, of microscopic cilia with which the surfaces of certain membranes are beset. Here only the base of the motor organ is attached. By the motion of the contractile fibres, and especially by muscular motion, solid parts of the body are approximated to each other, or fluids are impelled onwards in muscular tubes. By the motion of cilia, fluids and minute microscopic particles of solid matter are merely made to move over the surface of membranes; the fluids do not here fill the entire cavity of the tubes, nor do the membranes themselves contract. The motion due to contractile fibres prevails much more extensively through the body than the ciliary motion.

The muscular fibrous structure is distributed in three strata, the arrangement of which is connected with the earliest process of organisation. All the systems of the body are developed from the laminæ of the germinal membrane, which originally covers the yolk in the form of a disk; this membrane is formed of three layers, the

external or serous, the internal or mucous, and the middle or vascular layer : and when the embryonic portion has become separated from the rest of the germinal membrane by a constriction corresponding to the future umbilicus, the parts of the body endowed with animal or voluntary motion are developed in the external layer ; those endowed with organic or involuntary motion in the internal layer ; and in the middle or vascular layer is formed the heart, together with all the parts belonging to the vascular system, which, at a later period, ramify in the structures developed in the external and internal laminæ. The portion of the body formed in the external layer of the germinal membrane separates into the different structures of the animal nervous system, the osseous system, the system of voluntary muscles, and the skin. The portion of the body developed from the mucous layer separates into the different structures of organic life, namely, the fibrous structures forming the support of the different organs, such as the fibrous tunic of the intestinal tube, (the tunica nervea of the older anatomists,) the serous membranes, the mucous membranes, the muscular coat lying between the fibrous and the serous, and lastly, the organic nervous system.* This organic portion of the body includes the intestinal tube, the urinary and the generative apparatus, all of which have in nearly their whole extent an organic muscular layer, which is the sole cause of all the motions they exhibit. The proper pharyngeal muscles and the perinæal muscles, which are endowed with voluntary motion, and belong to the animal portion of the body developed in the external lamina, are not here included. Even the efferent ducts of the accessory glands of the organic system have a muscular coat continued on them from the muscular layer of the great tubes ; for, though the muscular coat of these ducts has not, it is true, from their delicacy, been demonstrated so plainly as the other membranes, yet its presence is certain : the ductus communis choledochus, the ureters, and the vasa deferentia have been seen to contract, both spontaneously and under the application of stimuli (see page 475). That the efferent ducts and their glands are originally developed from the walls of the tubes into which they open is an ascertained fact, at least, with regard to the glandular apparatus of the intestinal tube.

The muscles of animal life are distinguished from the pale muscular coats of the organs of the organic portion of the body, which are not subject to volition, not merely by their moving under the influence of volition, by their red colour, and their solidity, but even by the great difference of their microscopic character. We shall see that the primitive muscular fasciculi of the animal system present, under the microscope, transverse markings, and that the primitive fibres of these muscles have regular varicose enlargements following each other in

* Von Baer, *Entwickelungs-geschichte*. Scholien.

close succession ; while the fasciculi of the muscular coats of the intestines, urinary bladder, and uterus are destitute of those cross markings, and their primitive fibrils uniform, not varicose, threads. In the œsophagus the two systems border closely on each other ; the muscles of the pharynx belong to the animal system, those of the œsophagus to the organic : but the first fourth of the proper œsophagus receives an investment from a stratum of muscular fasciculi, descending on it in an arched form to a defined limit, in which Schwann has discovered the transverse markings and the fibrils of varicose structure ; these, however, belong to the pharyngeal muscular apparatus : no such fasciculi are met with on the rest of the œsophagus. [According to M. Ficinus* and M. Valentin,† the latter part of this statement is incorrect ; the muscular fibres of animal life descend on the œsophagus even to the cardia, and in man as well as many mammalia can be seen radiating out on the cardiac extremity of the stomach. Ficinus has also found the animal fibres in the intestine near the rectum, and in the stomach of birds.]

The animal system of perinæal muscles, with the sphincter ani, also comes into contact with the organic system of the intestinal canal at the anus. The same is the case in the urinary apparatus ; for, according to my observation, the red muscular fasciculi which surround the membranous part of the urethra present the cross markings, and their primitive fibrils are varicose ; while the proper muscular fibres of the urethra are pale, and without transverse markings, and their primitive fibrils like those of the intestines.

From the middle lamina of the germinal membrane is formed the vascular system, with the heart. This system, which, in the course of its developement, ramifies in the two other laminæ, is furnished with contractile fibres at certain points only ; namely, in the heart, at the commencement of the venæ cavæ and pulmonary veins, and in the lymph-hearts of reptiles and amphibia. All other parts of the vascular system are devoid of muscular fibres, though the whole arterial system possesses in its middle coat a highly elastic structure, which must not, however, on account of its extraordinary elasticity, be confounded with the contractile muscular fibre. The muscular tissue developed in the vascular layer of the germinal membrane, although its motion is not under the influence of the will, does not belong to the same class of muscular tissue as the involuntary muscles of the organic system ; it is red, and its whole structure is exactly similar to that of the muscles of animal life : the primitive fasciculi have the transverse markings, and the primitive fibrils are varicose.

The muscular fibres are not the only ones endowed with vital contractility ; there are other fibres, of quite a different nature, which

* De Fibræ Muscular. formâ et structurâ. Lips. 1836. p. 13.

† Repertorium, 1837. Bd. i. p. 86.

resemble those of cellular tissue both in microscopic appearance and in chemical properties, and are chemically wholly unlike muscular fibre. The parts in which this tissue occurs evince a slight and imperceptible degree of contractility, and are not capable of sudden contractions, such as can be excited in muscles: electricity also does not excite their contraction, but cold and mechanical stimuli cause it to ensue frequently with considerable rapidity. As an example of such parts, the tunica dartos of the scrotum may be instanced; there are, however, many others endowed with a similar property, which will be mentioned separately hereafter. How far this insensible contractility may be possessed by other tissues, it has not hitherto been possible sufficiently to investigate; for an insurmountable difficulty in the inquiry arises from the slight results produced where the contraction is not very marked. It appears, however, that just as there are very few membranes containing cellular tissue, that have not the property of undergoing a change of cohesion under the influence of chemical substances used in medicine, so a slight degree of contractility also is probably enjoyed by these tissues. Membranes which are permeable by fluids do not permit their passage during life: in disease this power of resisting imbibition is frequently lost, and after death it always ceases. Our ideas concerning the increased laxity of tissues and astringent substances, as far as they are founded on observations, presuppose a variability in the power of opposing the permeation of fluids, which, according to physical laws, must ensue.

The second primary kind of motion in animals, that of vibrating cilia, is observed on certain membranes both in the animal and in the organic portion of the body; and it is in some measure probable that it exists, at least in some of the lower animals, in the vascular system also, namely, in the interior of the vessels. It is seen in many of the lower animals in the animal part of the body, namely, over the entire surface. In the higher animals it is seen on the surface of the body during the embryo state only, as in the embryo of the frog; and, in some animals, in the larva state, as in the tadpole; [but it has been discovered by Purkinje to exist in the parietes of the ventricles of the brain, both in the embryonic and adult state of mammalia.] In the organic portions of the body the mucous membranes (not all of them) present it, even in the highest animals, up to man himself. It is possible that the motion of nutritive fluids which is observed in the lower animals where there is no heart and no distinctly contracting vessels, is, in all cases, merely the effect of the motion of cilia; and the circular motion of the sap in the cells of many plants may be produced in a similar way. The phenomena of this kind have been described at pages 45 & 155; they do not in any way tend to confirm the notion of a spontaneous motion of fluids.

CHAPTER II.

OF CILIARY MOTION.*

THE phenomena of ciliary motion were observed in the Mollusca by De Heide, Leeuwenhoek, Baker, Swammerdam, and Baster, although the mode of their production was not explained until a much later period. [The cilia on the surface of the infusory animalcules were distinguished by Leeuwenhoek,† who described their motion and use. They were afterwards observed by Baker,‡] De Heide and Leeuwenhoek noticed the currents on the surface of the branchiæ of Mussels; Swammerdam, Leeuwenhoek, and Baster observed the whirling motion of the embryo of Mollusca in the ovum. The former phenomenon has recently been minutely described by M. Erman§ and Dr. Sharpey, the latter by Carus.|| The cilia on the tentacula of the Plumed polype (*Plumatella*) had been described by Steinbuch, and more recently by Meyen. Gruithuisen¶ discovered them in the *Planariæ* and a freshwater snail; [Dr. Fleming had noticed them vibrating on the branchiæ of another gasteropod (*Tritonia*;) and Dr. Grant first recognised them as the cause of the motion of the embryos of Mollusca in the ovum, and of the ova (or rather embryos) of the *Polypifera* and *Sponges*.] The cilia of the *Medusæ* have been described by Tilesius, Eschscholtz, and Dr. Grant.] The ciliary motion has been further discovered by Ehrenberg to prevail through the whole group of invertebrate animals, which he names *Turbellaria*, (including the *Gordius*, *Nemertes*, *Planaria*, *Naidæ* fluviatiles, &c.) occupying the surface of their body, and he has seen it in the intestinal cavity of the Wheel animalcules and *Naidæ*. [Dr. Sharpey has discovered the existence of the ciliary motion in the *Actiniæ* and *Asterias*, and in the internal cavities of the *Echinus*, on the surface of which it has been noticed by M. Ehrenberg. Mr. Lister has described the ciliary motion as existing in the *Ascidieæ*. And very recently it has been observed on the exter-

* The principal writings on ciliary motion are those of Purkinje and Valentin, in Müller's *Archiv.* i. p. 391. ii. 159; their work, *De Phænomeno generali et fundamentalis motus vibratorii continui in membranis, &c.* Vratisl. 1835. 4; and a paper in the *Nova Acta Nat. Cur.* t. xvii.; Sharpey, in *Edinb. Med. and Surg. Journ.* vol. xxxiv. July 1830; *Edinb. New Phil. Journ.* vol. xix. July 1835; and *Cyclopedia of Anat. and Phys. Art. Cilia*; Grant, *Edinb. New Philos. Journ.* 1826; *Edinburgh Journal of Science*, 1827.

† *Contin. Arcan. Natur.* p. 382.—Dr. Sharpey's article, "Cilia," *Cyclopedia of Anat.*

‡ *On Microscopes.* London, 1743, p. 72.

§ *Abh. d. Acad. zu Berlin.* 1816, 1817.

|| *Nova Act. N. C.* t. xvi.

¶ *Salzb. Med. Zeit.* 1818. 4. 286.—*Nov. Act. N. C.* t. x.

nal surface of the Spermatozoa of the Newt by Mayer,* and of those of the land Salamander also by Wagner.†]

The first observations relative to the existence of the phenomenon in vertebrate animals were made by Steinbuch, who remarked the currents in the water around the branchiæ of the Batrachia, but did not recognise their cause, and sought in vain for cilia. Gruithuisen discovered the phenomenon on the tail of the larva of the frog; and Dr. Sharpey described the existence of the currents not only around the branchiæ, but over the whole surface of the body of the tadpole; similar observations with respect to the branchiæ were made by Huschke, Raspail, and myself. It remained, however, for Purkinje and Valentin‡ to make the important discovery, not only that the phenomenon in question was in the Batrachia, as in the invertebrata, dependent on the oscillation of cilia, but that it exists, from the same cause, on the surface of the mucous membranes of birds, reptiles, mammalia, and man. It appeared to be absent in fishes; it exists, however, in them also. I will now give an account of the most important facts relating to this subject, with some remarks upon them.

a. Of the different parts of animals in which the ciliary motion exists.

The ciliary motion has in different animals been observed on the external surface, in the alimentary canal, in the respiratory system, in the generative organs, [in the cavities of the nervous system, and on the surface of serous membranes.]

1. *The external surface* presents the ciliary motion in the Infusoria, in the coralline Polypifera (the Bryozoa, in contradistinction to the Anthozoa, § of Ehrenberg); [in the Actiniæ and Asterias also, according to Dr. Sharpey; in the Echinus, according to Ehrenberg;] in the Acalepha; in the Mussel (on the mantle); in the Gasteropods (snails), terrestrial and aquatic (over the whole surface); in the Turbellaria of Ehrenberg [and in the Spermatozoa]. In the higher animals the ciliary motion is not observed on the external surface, except in the embryo, and in the very young larvæ of amphibia. During the earliest period of the larva state, the whole superficies of the body was seen by

* Froriep's Notiz. 1836. No. 1089. p. 165.

† Fragmente zur Physiologie der Zeugung. München. 1836.

‡ Müller's Archiv. 1834; and afterwards in their work, De Phænomeno, &c.

§ [M. Ehrenberg (Symbolæ Physicæ, and Müller's Archiv. 1834, p. 578,) divided the polypi into two groups, the Bryozoa and the Anthozoa. The Bryozoa are those which have a perfect intestinal canal, with a ciliated surface (whence they are called ciliobrachiata by Dr. A. Farre, Philos. Transact. 1837). The Anthozoa have merely a digestive sac with one opening, and their surface is destitute of cilia. M. Ehrenberg has since made a further division of these Anthozoa. A similar arrangement of the Polypifera, showing the coincidence of a complete intestinal canal, with the presence of cilia on their surface, was given by Dr. Sharpey in his article, "Cilia," in the Cyclop. of Anat.]

Dr. Sharpey, and by Valentin and Purkinje, to present the ciliary motion; afterwards, the extent to which the phenomenon is observed, becomes gradually less, until it is confined to the root of the tail and the sides of the head; and when the extremities have become developed it has wholly disappeared.

2. *Alimentary canal*.—Purkinje and Valentin have discovered the ciliary motion in the alimentary tube of reptiles; but only at its upper part, namely, on the internal surface of the mouth, the Eustachian tube, the pharynx, and, in the chelonia (turtles and tortoises,) and serpents, in the œsophagus also. In the œsophagus of serpents the ciliary motion is described by the observers above mentioned to cease at the point where the longitudinal folds of the mucous membrane of the stomach commence; in the chelonia the phenomenon ceases to present itself at a defined line where the stomach commences. In mammalia and birds the ciliary motion does not exist either in the cavity of the mouth, or in the pharynx and œsophagus.

In the mollusca the ciliary motion prevails, according to Purkinje and Valentin, throughout the whole alimentary canal, and even in the biliary ducts; it was observed by Ehrenberg in the alimentary canal of Rotatoria (wheel animalcules) and Naides (a genus of annelida, or red-blooded worms); and Dr. Sharpey has seen it in the stomach and cæca of the Asterias, in the intestinal canal of Annelida, and in the stomach of Actiniæ; lastly, the movements of granules in the digestive cavity of the polypifera, which was described by Meyen and Mr. Lister,* are of this nature.

3. *Respiratory organs*.—The mucous membrane of the larynx, trachea, and bronchi, has been found by Purkinje and Valentin to present the ciliary motions in all the air-breathing vertebrata. In mammalia and birds the phenomenon commences at the glottis, not existing in the cavity of the mouth and pharynx in these classes. In birds it extends into the air-sacs which communicate with the lungs. The external branchiæ of the larvæ of the amphibia present the ciliary motion; but on the internal branchiæ, which these larvæ have in the second stage of their development, and on the branchiæ of fishes, the phenomenon is, as Dr. Sharpey observed, absent. It is probable that the external gills of the embryo shark and skate would present the ciliary motion. [Dr. Allen Thomson, however, failed to perceive any appearance of it on those parts in the skate.†]

The motion is universally present over the surface of the branchiæ of the mollusca, and also over that of the accessory branchiæ or labial appendages of the conchifera (mussels). But Purkinje and Valentin could not detect it on the inner surface of the pulmonary sacs of the

* Philos. Transact. 1834.

† Dr. Sharpey's article, "Cilia"; Cyclopædia of Anat. vol. i. p. 632.

pulmoniferous gasteropods (common snail and slug). They also failed to discover the slightest motion on the surface of the branchiæ of the true crustacea (crab or lobster). Steinbuch distinguished the cilia, and described their motion, on the arms of the *Plumatella*. Henle and I have seen the ciliary motion on the branchiæ of *Sabellæ* (marine annelida); [Dr. Sharpey has observed it on the gills of the *Serpula* and another annelide; and on the parietes of the visceral cavity, to which the water has free access, in the *Aphrodita aculeata* (sea-mouse), as well as in the *Asterias*, *Echinus*, and *Actinia*.]

4. *Nasal cavity*.—In this situation the ciliary motion is constantly present. It was discovered there by Purkinje and Valentin. In reptiles and amphibia, birds and mammalia, it occupies both the external and internal wall of the nasal cavity; and in mammalia the observers just named have detected it also on the mucous membrane of the sinuses opening into the nostrils, the frontal and maxillary sinuses, and in the Eustachian tube. In the rabbit the lining membrane of the lachrymal canal and sac presents no ciliary motion, though the phenomenon exists in the nasal cavity; the ciliary motion is also not present on the conjunctiva. This is certainly not what we should have expected, for had the ciliary motion existed on the surface of the conjunctiva, or even in the lachrymal canals and sac merely, it would have afforded an easy explanation of the absorption of the tears. The ciliary motion is very evident in the nasal cavities of fishes.

5. *Generative organs*.—In vertebrate animals the ciliary motion has been found by Purkinje and Valentin to occupy the mucous surfaces of the female generative organs only. It is observed in the oviducts, the uterus and vagina of mammalia (not in young animals); and it persists even during pregnancy on those parts of the uterus which are not occupied by the chorion. [Professor Wagner* could not detect any ciliary motion on a portion of mucous membrane taken from the upper part of the vagina of a woman labouring under gonorrhœa; and Dr. Henle† states that cilia do not exist on the mucous membrane of the genital organs of the human female lower than the middle of the neck of the uterus.] In birds, reptiles, and amphibia it extends to the very extremity of the oviducts. I have seen the phenomenon in mammalia, as well as in birds, reptiles, and amphibia. It is probable that the motion of the cilia has some share in effecting the transmission of the ovum to the oviduct in amphibia; how the ova reach the oviduct, the abdominal extremity of which in the frog and salamander lies so much higher in the abdominal cavity than the ovarium, is, it is well known, at present quite enigmatical; but it is possible that this object may be aided by the mucous membrane of the oviduct being protruded from the abdo-

* Froriep's Notiz. 1837. Bd. i. p. 227.

† Müller's Archiv. 1833, p. 113.

mental extremity of the tube, so as to turn the vibrating surface to the ovary, and to the ova escaping into the abdominal cavity. In fishes also the ciliary motion exists in the female organs of generation, namely, on the inner surface of the oviduct, extending very distinctly as far as the external opening of the generative apparatus.

In the mollusca, Henle found the ciliary motion distinct in the female organs of generation, that is to say, in the organ called by Cuvier the ovary of the snail, and on the inner surface of the cavities of the ovary of the mussel. The male organs do not present any ciliary motion in vertebrate animals, and it has not been observed in any organs of the invertebrata, which indubitably belong to the male sexual apparatus.

6. *Urinary apparatus.*—In the vertebrata the ciliary motion is entirely wanting in the urinary organs. But Purkinje and Valentin have detected it in the saccus calcareus of snails, an organ which opens upon the surface of the body near the anal aperture, and which, from containing uric acid, may be regarded as the kidney of these animals. Henle also has seen the ciliary motion in this organ. In the conchifera the ciliary motion has been observed by Purkinje and Valentin on the inner surface of the saclike organ described by Bojanus, which opens near the orifice of the ovaries: this organ has been compared to the kidney; but it might with equal reason be regarded as the testis, until some other organ is clearly proved to be the testis of these animals. [This question is now decided; the conchiferous mollusca are male and female; the organ hitherto generally supposed to be in all individuals the ovary, produces in one sex the ova, in the other a fluid containing spermatic animalcules. This was known to Leeuwenhoek, and was again discovered by Prevost in 1825, but the fact was overlooked until recently confirmed by Wagner.*]

7. [*The ventricles of the brain.*—The ciliary motion has been discovered on the lining membrane of the ventricles of the brain by Purkinje, who has with M. Valentin examined it in this situation in man, many mammalia, birds, amphibia, and fishes. It extends through all the ventricles of the brain, and all the cavities of the brain and spinal cord in the foetus and embryo.†]

8. [*The serous membranes* (the pericardium and peritoneum in the frog) have been stated by Mayer‡ to present the phenomenon, and the observation has been confirmed by M. Valentin.§]

From the review which we have thus taken of the parts which pre-

* [See Wagner's *Lehrbuch der Vergleichenden Anatomie*; and Siebold über die Spermatozoen der Wirbellosen Thiere, in Müller's *Archiv*. 1837, p. 381. The bivalves of the genus *Cyclas* are an exception to the order. They are hermaphrodite, each individual having distinct double ovaries and testes.]

† Müller's *Archiv*. 1836, 289, and Valentin's *Repert.* 1837, Bd. i. p. 156.

‡ *Supplemente zur Lehre vom Kreislaufe*, Pt. ii, p. 7. *Froriep's Notiz*. No. 1024.

§ *Repertorium*, Bd. i. p. 149.

sent the ciliary motion, it is evident that it is a phenomenon which exists very generally in the animal kingdom; but that the extent to which it prevails in the different classes of animals is very various. In no class of animals [except the crustacea? *] is it entirely wanting.

The vibrations of cilia are also the cause of the motions of the embryos of many animals in the ovum, and of the motion of the free ova (or, more correctly, embryos,) of several of the lower animals, as the Radiata and Polypifera. Cavolini observed the motions of the ova of Gorgoniæ; Tilesius, those of the ova of the Millepores; Dr. Grant, those of the ova of Campanulariæ, Gorgoniæ, Caryophylli, Spongiæ, and Plumulariæ. The ova, escaped from the capsules, move along with one end forward. Rapp discovered cilia likewise on the ova of the Corynæ. Dr. Grant has also discovered cilia on the embryos of Gasteropods, which are the cause of their motions in the ovum.

b. Of the phenomena of ciliary motion.

It requires a high magnifying power to perceive the ciliary motion in most animals. To see it, a very small piece of any mucous membrane on which it exists should be moistened with water and covered with a plate of glass, by which it is spread out, and its border rendered clearly visible. With the aid of a powerful microscope the phenomenon of the ciliary motion may then be seen. First, there is the appearance of an undulation, and the small bodies floating in the water are seen near the border of the membrane to be driven along in a determinate direction. With a still higher magnifying power, the cilia themselves may sometimes be recognised, although seldom very distinctly, on account of the great rapidity of the motion. Often the effect of the action of the innumerable moving organs is so great, that it is necessary to be quick in making the observation, lest the entire portion of membrane should escape from the field of vision. The influence of the ciliary motion on the fluids and small bodies which are in contact with the ciliated membranes may also be very well shown by strewing on the surface a fine powder. The motion of the cilia is so active on the branchiæ of the larva of the salamander, or of the mussel, that small portions of those organs, when placed in water, are regularly whirled round.

The motion of the cilia, having a uniform direction, gives rise to currents over the surface of the mucous membranes. The direction of these currents on most parts has been already determined by the labours of Dr. Sharpey, and of Purkinje and Valentin. The direction of the current in the trachea of a hen was found by Purkinje and Valentin to be from without inwards; in the oviduct it was from within outwards: the supposition, therefore, that the semen is conveyed to the ovum by

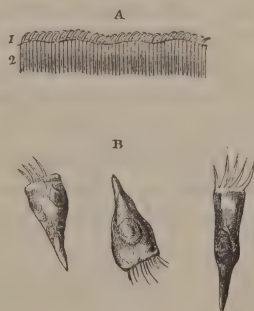
* See Dr. Sharpey's article, "Cilia," in the Cyclop. of Anat. vol. i.; the note at p. 628.

ciliary motion, is not capable of proof. On the inferior turbinated bone of a rabbit the current was ascertained by Dr. Sharpey to be directed from behind forwards; in the antrum it appeared to be directed towards the opening of the cavity. In the cavity of the mouth of the batrachian amphibia the current produced by the ciliary motion is, both on the floor and roof of the cavity, directed towards the œsophagus. At the palatal entrance of the nostril, in a lizard, the current on the inner side of the opening carried small particles of powder into it; on the outer side it carried them out into the mouth.

c. Of the organs which produce the ciliary motion.

The organs of the ciliary motion are, according to Purkinje and Valentin, delicate transparent filaments, varying in length from 0·000075 to 0·000908 of a French inch [from $\frac{1}{12307}$ to $\frac{1}{1016}$ of an English inch]. They are generally thicker at their base than at their free extremity: this is the form that they generally appeared to me also to present on the mucous membranes; on the branchiæ of a new genus of annelide, allied to the sabella, which exists in the Baltic, they were more club-shaped. [The cilia in invertebrate animals are generally cylindrical, acutely pointed filaments; but in the vertebrata, according to MM. Purkinje and Valentin, they are more or less flattened processes, of which the free extremity is in man and mammalia cut off or rounded; in birds and reptiles more pointed.* The cilia which these observers discovered in the ventricles of the brain of mammalia were, however, tapering pointed filaments, resembling those on the vibrating membranes of mollusca.†] It is very difficult to determine the form of the cilia, but easy to ascertain their presence. I have seen them very distinctly in the fresh-water mussel (*Anodon*), on the branchiæ of the annelide just mentioned, in the mouth of the frog, in the oviducts of rabbits, frogs, and fishes, and in the trachea of birds and mammalia; and I cannot understand how Treviranus (*L. Chr.*) could fail to discover them. The surface of the membranes which present the ciliary motion is, according to Purkinje and Valentin, composed of minute straight fibres, arranged parallel to each other, and united by an intermediate connecting matter (see fig. 54, A). A similar stratum of fibres, how-

Fig. 54.‡



* *Nov. Act. Nat. Cur.* t. xvii. pt. ii. p. 846.

† *Repertorium für Anat. & Physiol.* Bd. i. p. 158.

‡ [Fig. 54, A, from Valentin, *Nov. Act.* t. xvii.; cilia vibrating on mucous mem-

ever, exists on the surface of the mucous membrane of the jejunum of the turtle, on which there is no ciliary motion. If we understand MM. Purkinje and Valentin, these fibres are arranged perpendicularly upon the surface of the mucous membrane. [These are the same nucleated bodies that have been found by M. Henle forming the epithelium of various mucous membranes, as described and figured at p. 435 (fig. 32). From the form of the component particles, he calls the epithelium which it forms, the "cylinder epithelium," to distinguish it from the epithelium which is formed of flattened cells (see p. 435, fig. 31). In membranes which present the ciliary motion, the epithelium is formed of the cylindrical particles, on the free extremity of which the cilia are seated (see fig. 54, B). The cylinders of the ciliary epithelium of the nasal cavities measure about $\frac{1}{7\frac{1}{2}}$ of an English line in length. Their mean length in the uterus is $\frac{1}{10\frac{1}{5}}$ of an English line. The length of the cilia which these cylinders bear in the Fallopian tubes is $\frac{1}{50\frac{1}{5}}$ of an English line.* M. Henle describes the cylinders of the ciliary epithelium as containing each a nucleus, like the particles of the epithelium in other parts. The account which M. Valentin gives of the separated cylinders is somewhat different. "If," he says, "we scrape from the Schneiderian membrane of the horse some of the half fluid mass which covers it, and examine it with the microscope, we shall perceive a number of bodies, like pedunculated vorticellæ, consisting of an elongated cylindrical body, rounded at its posterior extremity, from the centre of which a delicate, soft filament issues, and more flattened at its anterior extremity, on which from six to thirteen cilia are seated in a circle upon a slightly arched surface. Within the cylinder, and beneath the general granulated investment, are seen granular striæ, probably muscular fibres, for the movement of each of the cilia. The same parts may be distinguished in the ciliary epithelium of the trachea and uterus, (in which Purkinje also has seen them.)"†]

The researches of Ehrenberg have made us most intimately acquainted with the cilia as they exist in the infusoria. In the genera *Stylonychia* and *Kerona*, which are of large size, he discovered that each of the revolving cilia has a bulbous enlargement at its base; and he satisfied himself that a slight turning of the bulbs upon their fixed points causes the extremity of the cilia to move round in larger circles, each of the cilia describing a cone, the apex of which is the bulb. In the polygastric infusoria the cilia sometimes occupy the whole surface of the body; sometimes are

brane of trachea of rabbit: 1, cilia; 2, fibres of epithelium.—B, from Henle, *Symbolæ*, &c.; cylinders of epithelium with cilia, abraded immediately after death from the trachea of a cat.]

* See Henle, *Symbolæ ad Anat. Villor. Intest. &c.*; and Müller's *Archiv.* 1838, p. 114.

† Valentin's *Repertorium*, 1837, p. 267.

entirely absent; and in other instances are confined to the circumference of the mouth. When they are distributed over the whole surface, Ehrenberg found them very regularly arranged, generally in longitudinal, but frequently also in transverse series. This arrangement of the cilia in rows has also been some few times observed by Purkinje and Valentin; and the wave-like motion of series of cilia, which they observed, also renders it probable that the cilia are thus arranged. The rotatory organs of the Wheel animalcules do not, according to Ehrenberg, differ essentially from other cilia. The Hydatina senta has seventeen rotatory organs arranged in a circle, each organ consisting of six cilia, which are seated upon a roundish muscle. The muscles are surrounded by sheaths, and fixed by two ligamentous fasciculi to two points of the general investment of the body.* The same organs, when not aggregated together, as in the wheel animalcule, do not give rise to the appearance of rotatory motion.†

d. Nature of the ciliary motion.

In inquiring into the nature of the ciliary motion, we have first to consider its duration and its connection with other vital phenomena. It continues, after death, at least as long as the animal tissues retain their irritability, and often much longer. In frogs and lizards it ceases, according to the observation of Purkinje and Valentin, in from one to two hours after death; in a fresh-water tortoise, the *Emys Europæa*, it continued in different parts from nine to fifteen days after decapitation. It is true the muscles preserved their irritability, and reflex movements could be excited for seven days; but the ciliary motion continued equally long in parts which had been quite separated from the body of the animal and been placed in water. In birds and mammalia Purkinje and Valentin found that the vibrations of the cilia continued from three quarters of an hour to four hours. Light has no influence on the motions of the cilia; but the influence of heat is considerable. The ciliary motion will continue in mammalia and birds, although the parts in which it is seated be immersed for a moment in water of a temperature of $180\frac{3}{4}$ ° Fahrenheit; but, if the immersion be protracted for a longer period, the motions of the cilia are abolished. The discharge of a Leyden jar does not put a stop to the motion in the bivalve *Unio*, nor does the influence of a galvanic battery of thirty pairs of plates, except at the spot where the wires are applied; and the cessation of the motion there is owing to the decomposition of the tissues. The ciliary

* Abhandl. der Acad. zu Berlin, 1830.

† In a second paper, published in 1831, Ehrenberg has pointed out many variations in the structure of the rotatory organs.

motions are not affected by prussic acid, extract of aloes or belladonna, catechu, musk, acetate of morphia, opium, salicin, and strychnine, nor by decoction of capsicum, even though the most concentrated solutions of these substances be used. The salts of alkalies, earths, and metals, the alkalies and the acids, put a stop to the motion after a longer or shorter period, according to the strength of the solution applied. Blood maintains the cilia in activity longer than any other fluid; but the serum of the blood of vertebrate animals causes the ciliary motion in mussels to cease immediately; bile also puts a stop to the ciliary motion. It is very remarkable that those substances which have a particular action on the nervous system—the narcotics, namely,—have not the slightest influence on the ciliary motion, which is thus distinguished as a peculiar phenomenon not dependent on nervous energy. Purkinje and Valentin have killed pigeons and rabbits by means of prussic acid and strychnine, either introduced into the pharynx or inserted into fresh wounds of the skin; and they never perceived the slightest change in the ciliary motion in consequence of the poisoning, although they used the precautions both of not opening the animals before all motion had ceased in every part of the body, and also of waiting until pinching the limbs no longer excited automatic movements. To render the result still more certain, they, in their experiments on pigeons, killed a second bird, of the same kind and age, by bleeding; and the differences which were observed with reference to the ciliary motion in those experiments were only such as were owing to the individual peculiarities and age of the animals, and the peculiarities of the parts examined. There was, in all cases, the same absence of all effects from the narcotisation.* These latter experiments are evidently less conclusive as to the independence of the ciliary motion from the nervous system than those in which the poisonous substances were applied directly to the vibrating surface; for in frogs killed by narcotics the muscles and nerves retain their susceptibility of the influence of stimuli locally applied for a long period, while both nerves and muscles to which narcotics are directly applied soon lose their irritability. The heart alone is an exception to this rule; it continues to beat for a long time after solution of opium or of the extract of *nux vomica* has been applied to its external surface, but is immediately paralysed when the same poison is applied to its internal surface.

We do not regard the minuteness of the vibrating organs in comparison with the primitive fibres of the nerves as any argument against their phenomena being dependent on the nervous system; for the muscular fibrils themselves are so much more minute than the nervous fibres, the latter fibres are distributed in such small number in the muscles,

* Müller's Archiv. 1835, p. 159.

and the mass of muscular substance which is seen by means of the microscope to intervene between the nervous fibres is so great, that the existence of an influence exerted at a distance is a necessary supposition in accounting for the action of the nervous fibres on muscles. Moreover, there are parts in which, though not in the muscles, a much more minute ramification of the nervous fibres appears to take place.* The persistence of the ciliary motion, however, after the direct application of narcotic poisons, sufficiently proves the peculiarity of this phenomenon, and its independence of any immediate influence of the nervous system. An equally important fact in relation to this question is, the existence of the ciliary motion on the surface of the so-named ova of poly-piferous animals, which are however the animated, though undeveloped embryos. The extreme conditions of the phenomenon afford here the most interesting subject of comparison: the lowest condition is that of the ciliary motion on the undeveloped embryos of polypi; the most perfect that of the motion of the rotatory organs of the wheel animalcules. In the former instance we have the phenomenon taking place on membranes devoid of special structure, and allied to this condition is that of the vibratory motion of cilia on the mucous membranes of the higher animals, which is not arrested by the action of strychnine and other narcotic poisons; the motion of the cilia of the rotatory organs, on the contrary, is effected distinctly by muscular action, and is subject to the will; hence certainly dependent on the nervous system: strychnine also, as Ehrenberg has shown, arrests this form of ciliary motion.

The question now arises, Does the ciliary motion throughout the animal kingdom owe its production to a very delicate contractile tissue lying at the base of the cilia, and contracting after the manner of muscular fibres, as is the case with the rotatory organs of the wheel animalcules? Does this contractile tissue of the wheel animalcules (rotatoria), which Ehrenberg has discovered, constitute a peculiar system, forming part in the vibrating membranes even of the higher animals, the delicate structure of the infusoria being preserved in the cilia, while all other tissues of the higher animals have a coarser structure? Or is the motion of the rotatory organs of the wheel animalcules alone allied to muscular motion, and the ciliary motion of all other animals essentially different? I must give Ehrenberg's own words in describing the mechanism of the ciliary motion of the rotatoria. "If the creatures are observed when they commence their motion, there is always seen a distinct extension and retraction of the curved cilia, a true grasping movement (*greifen*), which however is soon succeeded by the rotatory motion, which is a totally different kind of movement. The grasping

* See page 604.

motion is seen likewise when the animalcules are made to die in a tetanic state, by putting strychnine into the water; the action of the rotatory organs then gradually ceasing, and the proper rotatory motion first." Ehrenberg endeavoured to explain the phenomenon in the following manner: "Each of the cilia is moved separately by the muscle situated at its base, and single muscular bands may probably go simultaneously to many or perhaps all the cilia of the same series, and give them all a motion towards one side. If, now, this one muscular band is opposed by a second attached to the opposite side of the bulbous root of the cilium, if the two are fixed to the cilia at somewhat different heights and act alternately, an alternate motion in four different directions will result; in consequence of which the free extremity of each of the cilia will be made to move in a circle, the entire cilium describing a cone, the apex of which is at the base of the moving filament. If during this motion of the individual cilia, the rotatory organs be regarded partially or entirely from the side, the cilia will be alternately nearer and more distant from the eye, and will consequently be alternately seen distinctly and indistinctly. This alternation in the degree of distinctness of the single cilia appears to me," says M. Ehrenberg, "to be the cause of the apparent rotatory motion of the entire organ; for such a motion of the cilia must certainly give rise to the appearance of active motion of the whole circle." We can easily understand how a muscular action such as Ehrenberg supposes to be exerted would cause the cilia to describe a cone; for the recti muscles of the eye of the higher animals can move the eyeball in a similar manner. In fact, the voluntary power of the wheel animalcules over their rotatory organs and the motor apparatus demonstrated by Ehrenberg, place it almost beyond a doubt that the motion of those organs belongs to the class of the true muscular motions. But how is it with the ciliary motions of the mucous membranes which are not subject to the will, and continue unaffected when the animals presenting them are poisoned by narcotics, and which are not affected even by the local application of strychnine or other narcotics? Again, how can we account for the existence of the ciliary motion on the ova of corals? Do these ova retain a portion of the vital energy which was infused into them when they were exposed to the vital influence of the ovary; and is it this remaining portion of vital energy which they thus manifest for a certain period, just as is the case with separated portions of mucous membrane taken from any of the higher animals? Are these vital phenomena analogous to the motions of the ovi-capsules of the *Cercariæ* observed by Bojanus and Von Baer? (See p. 17.) It is much more rational to regard these ova as animated, though undeveloped embryos. However this may be, it appears to us certain that, in the present state of our knowledge, the ciliary motions of the rotatory organs of the wheel animalcules must be

considered as different from the vibratory motions of the cilia of the mucous membranes. The former are subject to the influence of the will; the latter are independent both of the will and of any direct influence of the nervous system. In the rotatory organ the cilia are apparently passive, and the muscular apparatus is alone the active agent in producing the motion. No muscular apparatus has at present been discovered in connection with the cilia of the mucous membranes and those of the surface of the infusoria; and it is not at present known whether the cilia themselves move and bend, or whether they act as mere oars by virtue of a contractile tissue at their root. Meyen has seen the cilia of the *Leucophrys sol* (a polygastric infusory animalcule) continue to move when separated from the animal. Gruithuisen has observed the cilia of *Planariæ* in the separated state, and has seen them continue to move in parts where the substance of the animal was undergoing decomposition. [One kind of motion of the cilia described by Purkinje and Valentin* is that of uncination, the cilia becoming flexed, particularly near their point, as represented at fig. 54, A. Dr. Sharpey, too, says, the cilia most commonly "have a fanning or lashing motion; that is, the cilium is bent in one direction, and returns again to its original state;" and "the more elastic cilia," he says, "when their motion abates in intensity, appear sometimes to bend only near the point, the base and adjoining part remaining motionless."†] On the other hand, some animals present organs acting like oars or paddles, which in their involuntary and constant action greatly resemble cilia, but yet differ from them in their form; and the motions of these organs can scarcely be explained except by the presence of a contractile tissue at their root. In the genus *Beroë* (one of the *Acalephæ*) there are, according to Dr. Grant's observations, bands running longitudinally from the mouth to the anus, each bearing forty laminae, which are the organs of motion or cilia. These laminae are formed of parallel fibres connected together by a membrane. Indeed, the laminae, which are very easily seen with the naked eye, constantly moving at the abdominal surface of the *gammarus pulex* and other of the lower crustacea, must be referred to the same class of organs, although the motions of these laminae are certainly effected by muscles,—a different tissue perhaps from that which produces the ciliary motions on the mucous membranes.

In the present state of our knowledge, thus much may be advanced:

1. That the ciliary motion of the mucous membranes is due to the action of some unknown contractile tissue;
2. Which lies either in the substance of the cilia or at their base;

* Nov. Act. Nat. Cur. vol. xvii, pt. ii.

† Article "Cilia," *Cyclopedia of Anatomy*, pp. 634, 635.

3. That this tissue resembles in its contractility the muscular and other contractile tissues of animals ;

4. That its properties in so far agree with those of the muscular tissue, at all events with that of the involuntary muscles of the heart ; and with the vibrating laminæ of the lower crustacea, that the motions which it produces continue without ceasing with an equable rhythm ;

5. That its properties agree also with those of the muscular tissue of the heart, in its motions continuing long after the separation of the part from the rest of the animal body ;

6. That this tissue differs essentially, however, from muscle, in the circumstance of its motions not being arrested by the local application of narcotics ;

7. That the ciliary motion presents itself under conditions where it is not probable that a complicated organisation exists, namely, in the undeveloped embryos of polypiferous animals.

The circumstance of the ciliary motions not being immediately dependent on the influence of nerves, constitutes a point of resemblance between them and the oscillatory motions of certain plants, for example, the *Oscillatoria*. How far this comparison is correct must be determined by further research. But, however this may be, there certainly exists in the mucous membranes that present the ciliary motion, an active force which regulates the mode of action of these microscopic organs, since the cilia are very frequently observed to act simultaneously in regular series. There is here a force, the influence of which extends beyond individual cilia ; for though the simultaneous action of a series of cilia producing waves might be explained by supposing many cilia to be attached to one contractile band, yet there is also frequently observed a certain remission and acceleration of the ciliary motion over considerable tracts of a vibrating membrane, which must have a more general cause. I have sometimes seen a total rest of the cilia for a considerable interval over a large extent of the surface of the branchiæ of an annelide allied to the genus *Sabella*, which I brought with me in sea-water from Copenhagen, this state of rest being again succeeded by a state of activity. Analogous phenomena are frequently enough observed in the vegetable kingdom ; they are not necessarily therefore to be referred to a variation in the nervous influence.

The explanation of the production of currents by the ciliary motion is also attended with difficulty. The mere vibration of cilia from one side to another cannot give any particular direction to a fluid. The motion of the cilia, too, in a conical space, which, according to the observation of Purkinje and Valentin, is the most frequent kind of motion, can merely give rise to the motion of the fluid in a circle around the cilium. For the cilia to give rise to a current of the fluid in a certain direction, it is necessary that they should strike and bend in one direc-

tion; such, indeed, was the motion which Purkinje and Valentin observed sometimes, and that which I saw in most cases. But even with this motion it is necessary, to produce a current, that the cilia in returning to their erect position should present a smaller surface to the fluid than they do in making the stroke. [According to the observation of MM. Purkinje and Valentin,* it is the return of the cilia from their bent to the erect state which gives the impulse to the water, and produces the current.]

CHAPTER III.

OF THE MUSCULAR, AND THE ALLIED MOTIONS.

1. *Of the contractile tissues.*

IF we leave out of consideration the enigmatical tissue which is the cause of the ciliary motion, four forms of contractile tissue may be distinguished; namely, the contractile tissue of vegetables, the contractile tissue of animals which yields gelatin by boiling, the arterial contractile tissue, and the muscular tissue.

a. *Of the contractile vegetable tissue.*

The most remarkable of the phenomena of irritability presented by plants have been already described at page 40. We have here merely to institute a comparison between the contractile tissue of plants and that of animals.

The leaves of the sensitive plant (*Mimosa sensitiva*) are supported upon a long petiole, at the base of which, as well as at the junction of each leaflet with the petiole, an elongated intumescence exists, the seat of the power by which the petiole and leaflets are moved. In the natural state during the day the petiole is elevated, the leaves expanded, and the intumescence elongated, and equally convex superiorly and inferiorly. (Fig. 55. 1.) But at night, or when irritated, the petiole is depressed, the leaves applied to each other in pairs, and the intumescence at the base of the petiole curved so as to be convex superiorly, concave inferiorly (as at fig. 55. 2). The structure of this intumescence has been investigated by M. Dutrochet. He [formerly]†

Fig. 55.



* Nov. Act. lxvii. pt. ii.

† Recherches Anat. et Physiol. sur la structure intime des Animaux et des Végétaux. Paris, 1824.

described it to be in greater part composed of globular cells arranged in longitudinal series, but separated from each other by considerable intervals, the interspaces being occupied by much more delicate cellular tissue which contained numerous dark bodies. The centre of the intumescence he stated to be traversed by tracheæ which maintained the vascular communication between the leaves and stem. [Professor Müller, believing from M. Dutrochet's account of his experiments that the curving of the intumescence was probably owing to the approximation of rows of the globular cells, remarked that, were such the fact,] a great similarity would seem to exist between the contractility of plants and animals; there being, however, this difference, that the elements, which in animals attract each other to produce the contraction, form continuous threads, while in the *Mimosa* they are separated from each other by intervals. [More recently,* however, M. Dutrochet has given a different account of the structure of the motor organ of the *mimosa*. According to his later description, the external portion of the intumescence is seen in a transverse section to be formed of hexagonal cellular tissue, which, with the exception of its most internal cells, which are filled with air, contains a fluid coagulable by acids. Within the cellular portion is a ring formed of tubular fibres; within this again a thin layer of tubes and tracheæ; and in the centre a bundle of fibres similar to those of the layer within the cellular substance. When, by a longitudinal section the upper half of the intumescence is removed, the lower half, which remains, becomes permanently curved, so as to throw the petiole upwards. When, on the other hand, the lower half is removed, the intumescence curves so as to depress the petiole. The facts which M. Dutrochet has ascertained relative to the properties of the different tissues composing the intumescence are the following:—A segment cut from the outer cellular portion, when placed in water, becomes curved with the concavity inwards, whether the water be deprived of its air or not. A portion of the fibrous layer also becomes curved in the same direction when immersed in water containing air, but remains straight if the water have been deprived of its air. A leaf of *robinia pseudo-acacia*, placed in water containing air, presented the phenomena of periodical sleep, as in the air; but, in water which contained no air, it remained permanently in the position which the plant has in the air during day. A sensitive plant also did not sleep in the vacuum of an air-pump. From these facts M. Dutrochet concludes that the change to the position of sleep must be effected by the fibrous tissue, and that it is the cellular tissue which causes the expansion of the leaves and elevation of the petiole during the day. M. Dutrochet now proceeds to inquire how the cellular and fibrous parts of the intumescence respec-

* Mém. pour servir à l'Histoire Anat. et Physiol. des Végétaux et des Animaux, 1837.

tively produce the results which he thus traces to their action. Now, the cellular layer of the intumescence has its cells larger externally than internally; hence each portion of its circumference might be expected, if rendered turgid by endosmose, to have a tendency to bend towards the axis of the petiole, the larger cells being more distended than the smaller; and it is thus, according to M. Dutrochet, that the water acts in causing a segment of the cellular portion of the intumescence to become curved.

The cause which influences the motion of the plants so as to induce the expansion of the leaves and rising of the petiole is the augmentation of light during the day; the light favours the ascent of the sap, and thus must produce turgescence of the cellular portion of the motor intumescence. Each portion of the cellular cylinder in the mimosa has a tendency to curve towards the centre or axis of the petiole; but the lower part is the thickest, and hence the tendency will there be strongest, and will, when the intumescence is rendered turgid by the influence of light, cause the elevation of the petiole. If, however, the lower half of the intumescence be removed, the tendency of the upper half, being no longer counterbalanced, will come into play, and depress the petiole: if the upper half only is removed, the lower will act with increased force, and raise the petiole still more, as in the experiment already mentioned.

The fibrous tissue has the property of curving when submitted to the action of atmospheric air or oxygen ("par oxigenation"). Each segment of the layer of fibrous tissue has a tendency to curve with the concavity towards the axis of the petiole; the central bundle of fibrous tissue has, M. Dutrochet supposes, though he does not demonstrate this, a tendency when oxygen unites with it to curve downwards, in the same direction therefore as the upper part of the hollow cylinder of fibres, with which it would co-operate in depressing the petiole, overcoming the force of the lower portion of the fibrous layer, the tendency of which is to raise the petiole. It is thus, according to M. Dutrochet, that the depression of the petiole is effected in the evening, when the turgescence of the cellular portion of the intumescence becomes less from the absence of light; while oxygen, having accumulated in the fibrous tissue, increases its incurvating tendency. Even the fibrous tubular tissue is supposed by M. Dutrochet to become curved by virtue of a state of impletion caused by the union of oxygen with the contents of the tubular fibres. The tubular fibres of the fibrous layer of the intumescence increase in size, he says, from within outwards; and hence, when distended, would give to each part of the fibrous cylinder a tendency to curve towards the axis of the petiole.

The depression of the petiole, and the folding of the leaves of the mimosa and other plants when irritated mechanically, or by heat or

acids, is, according to M. Dutrochet, also the result of the same action of the fibrous tissue, which becomes oxygenated whenever the plant is irritated in any way, it being a fundamental theory with this physiologist that excitation is in all cases merely oxydation of the living tissue, animal or vegetable.

In other plants,—as the *Phaseolus vulgaris*, or haricot bean, and the *Robinia pseudo-acacia*,—though the structure of the motor intumescence is generally the same, there are differences in the relations of the cellular and fibrous tissues which render M. Dutrochet's theory insufficient to explain their action. These difficulties he attempts to overcome by other suppositions, which are not always satisfactory. Professor Müller, opposing the idea of endosmosis and expansion being the cause of the motion of the intumescence, remarks]: The sudden expansion of the cellular tissue is not demonstrated, nor is it indeed probable; the cells cannot so rapidly attract through their parietes the fluids necessary to produce their turgescence; and Dutrochet does not state that the portions cut from the intumescence became expanded, but that they became curved; these reasons induce me to regard the explanation of these motions of vegetables by contraction as more probable. We are acquainted with no other instance of rapid motion by expansion than that of erection, which is effected by the effusion of a fluid into cavities previously collapsed; but such a rapid effusion into the closed cells of the intumescence of the mimosa cannot easily be conceived; nor can an active, rapid expansion of the parietes of the cells be imagined to take place.

Supposing the phenomena to be owing to contraction, two modes of explaining them might be adopted. Either we may suppose that there are two active parts,—one acting under the influence of the general vital stimuli, and producing the elevation of the petiole, but ceasing to act when the plant receives any shock,—the other evidencing its irritability only under the influence of external shocks or irritation, and causing the depression of the petiole; or we may suppose the petiole to be kept erect during the waking state by a vital action of the intumescence, and external stimuli to cause the depression of the petiole by annulling for a period the vital contractility, and allowing an elastic force to come into play. Were this latter explanation correct, the contractility of plants would be distinguished from that of animals in being abolished by disturbing influences, and not excited by them as in animals,—that is to say, in beings furnished with nerves. The former explanation is, however, the more probable, since the depression of the petiole excited by external shocks has been observed by many physiologists to resist any attempt to raise it; it is, therefore, an active movement.

To excite the motion of the leaflets and petiole of the mimosa, it is

not necessary that either the intumescence itself, or even the leaves, should be touched. The stimulus may be applied to a more or less distant part. [Even the roots transmit the excitation to the leaves; M. Dutrochet moistened a small portion of the roots of the mimosa with sulphuric acid, and, before there was time for absorption of the acid to have taken place, the leaves became folded.] M. Dutrochet has satisfied himself that the transmission of the excitation is effected by the woody part of the plant, not by the cortical or medullary parts; for these he found might be entirely removed, and irritation above or below the spot would still be propagated beyond it. The excitation extends gradually from the points to which the stimulus is applied; first the nearest leaves, and then the most distant, becoming folded. The excitability is greatly influenced by light and temperature, as well as by the presence or absence of atmospheric air. Both the excitability and mobility of the mimosa are lost after a few days, when the plant is deprived of light; the susceptibility of external stimulus being lost before the movements of sleep and waking cease. Variations in the temperature of the atmosphere also cause the quickness of the transmission of the excitation from one part of the plant to others to vary, and at $47\frac{3}{4}^{\circ}$ Fahr. no motions can be excited.

b. Of the contractile tissue of animals which yields gelatin by boiling.

The first traces of vital contractility in animals are presented by a tissue so similar in the structure of its fibres, as well as in its chemical properties, to cellular tissue, that it might almost lead us to regard them as identical, and to ascribe to cellular tissue not merely the property of elasticity which it retains after death, but also an organic contractile power. Until more is known of the tissue in question, we designate it the contractile tissue yielding gelatin, by which we sufficiently distinguish it from the fibrinous muscular tissue.

In addition to their transparency and smoothness, the fibres of the cellular tissue, which have been described at page 432, have a very peculiar character in their wavy disposition. When not artificially extended, they are never straight, but have an arched or waving direction (plate ii. fig. 4). The fibres of each primitive fasciculus are, however, always parallel; it is the fasciculi which are thus waving. This character of the cellular tissue is owing to its great elasticity. If the fasciculi be extended and straightened, they return, as soon as the extension is remitted, to their original curved state. A chemical examination of cellular tissue, after it is freed by washing from blood or lymph, shows that it belongs to the class of tissues that are converted by boiling into gelatin; and its fibres are, in this circumstance, again distin-

guished from muscular fibre which belongs to the albuminous tissues.* This is important, as affording a means of distinguishing the contractile cellular tissue from those muscular fibres which have not the varicose structure; for example, the muscular fibres of the uterus. The latter fibres, however, differ from the fibres of cellular tissue by another character, namely, by the want of the curved and waving position of their fasciculi.

The contractile property of the tissue allied to cellular membrane has been long known; but it has, in many parts of the body, been frequently confounded with muscular action; and, on the other hand, in consequence of the slight change of diameter produced by this kind of contraction, the phenomenon has by some been quite neglected, or even denied to exist. To verify the existence of the phenomenon in question, it is best to study it first in those parts in which it is presented in the most marked degree, and in which the tissue can be submitted to an accurate microscopic and chemical analysis. The tunica dartos has a very active contractile property, which is most frequently excited by cold. The structure of this tunic and the nature of its tissue have been recently determined by M. Jordan. The following is extracted from his paper.†

At the point where the surface of the scrotum begins to present folds or wrinkles, the subcutaneous cellular membrane likewise changes its aspect and structure; the adipose tissue so abundant on the mons Veneris is suddenly lost, and in its place there is seen in men who have strength of body, and whose scrotum is very rugose, a fibrous tissue of reddish colour. The fibres of this tissue are extensile and elastic, and are collected into small fasciculi, and these again into thicker bundles. These bundles of fibres run from above downwards, at right angles, therefore, with the folds of the scrotum, with which they are so closely connected, that it requires great trouble and caution to separate them. The larger fasciculi do not all follow a parallel course; but, by frequent anastomoses, a portion of the fibres being given off from one fasciculus to another, form a dense and strong reticular tissue, of which the numerous elongated meshes have all their longest diameter directed from above downwards. This tissue is, like the folds of the skin, most distinct on the anterior surface of the scrotum, and generally cannot be distinguished on the posterior surface; it exists in young children, and even in newborn infants. Similar reddish fibres are found under the skin of the penis; but here they form a more irregular and much thinner tissue. Besides the fibres already described, the dartos contains many long and narrow cylinders of a faint yellow colour, very elastic,

* See the Appendix to the chapter on Nutrition.

† Müller's Archiv. 1834.

but little ramified, and following a course from above downwards. M. Jordan convinced himself by injection that these are branches of the external pudic and posterior scrotal arteries. Between the skin and the dartos there is no cellular tissue; the two are so intimately connected, that the one must follow the movements of the other. But between the inner surface of the dartos, and the cremaster and tunica vaginalis communis, there lies a quantity of cellular tissue, so loose that, as M. Jordan has observed in experiments on dead bodies and living animals, the testis with its coverings can be drawn up towards the inguinal ring, leaving the lower part of the scrotum empty.

The primitive fibres of the fasciculi which compose the tunica dartos are excessively delicate and elastic. When examined with the compound microscope, they are seen to be uniform cylindrical filaments, with a serpentine waving disposition. Their diameter, as determined by M. Jordan, varied from $\frac{1}{2000}$ to $\frac{1}{1111}$, and in the mean was $\frac{1}{1430}$ of an English line. The fibres of cellular tissue had the same diameter. On the other hand, the fibres of the dartos differ in diameter from the muscular fibres. The varicose muscular fibres are smaller, the muscular fibres of the colon, which are not varicose, are larger, and those of the iris are much more minute. But, independently of their size, the fibres of the dartos exactly resemble the fibres of cellular tissue in their serpentine disposition and elasticity, and are by these characters distinguished from ordinary muscular fibres. The reddish-grey colour, however, which the fibres of the dartos in a mass present, and the regularly longitudinal direction of their fasciculi, distinguish them, although they form a reticular tissue, from the fibres of cellular tissue, of which the fasciculi have a whitish-grey colour, and are interlaced in all directions. It is a question, therefore, whether the similarity in the appearance of these fibres under the microscope is sufficient to identify the dartos with cellular tissue. The decision of this question is rendered still more difficult by the circumstance of the fibres of tendon, which is in its properties so totally different from the dartos, being very similar, when seen with the microscope, to those of cellular tissue (see plate ii. fig. 5). Another difficulty is the existence of a class of muscles of which the primitive fibres are not varicose like those of the muscles of the limbs, &c. but uniformly cylindrical, in which character the fibre of the dartos resembles them, and thus far seems to stand very near to them. Moreover, the motion of the dartos, though generally excited by the stimulus of cold, yet sometimes is produced by certain internal conditions of the nervous system; the same state of the nerves giving rise sometimes to the contraction of a true muscle,—the cremaster,—as well as to the wrinkling of the scrotum; which latter phenomenon can be proved distinctly not to depend on the action of the cremaster.

On the other hand, traces of contractility are displayed in true cellular tissue in other parts of the body; for example, in the subcutaneous cellular tissue between the folds of the prepuce, which frequently in irritable individuals contracts very strongly in the cold bath. The phenomenon of "*cutis anserina*" seems to be one of an analogous nature. The sudden erection of the nipple is probably produced in the same way; for I have good grounds for questioning the correctness of the common opinion, that the latter phenomenon is the result of vascular turgescence, or true vascular "erection." In the first place, the nipple does not contain any of the spongy tissue which forms the corpora cavernosa penis; those anastomosing veins and sinuses, and the arteriæ helicinæ projecting into the venous sinuses, which characterise the true erectile tissues (see page 227). Secondly, the erection of the nipple is perceptible not only in females when it is handled during the existence of the sexual excitement, but also in men, quite independently of sexual feeling. Thirdly, the nipple in man becomes erected almost instantaneously and quite visibly when it is suddenly and roughly handled in one's own person; the same takes place in a less degree also when the nipple is exposed to the contact of cold water, and in a more marked degree when the individual suddenly enters a cold bath. Fourthly, the erection of the nipple is not attended with any increased fulness; on the contrary, while it is becoming erect, which occupies a few seconds only, it becomes narrower, and loses in breadth what it gains in length. Now, in all these circumstances there is great similarity to the phenomena of the elevation of the cutaneous follicles in "*cutis anserina*," and to those of the contraction and wrinkling of the prepuce in cold water. The erection of the nipple is, therefore, most probably the effect of contraction of the subcutaneous cellular tissue which surrounds it. It is remarkable that the contractile cellular tissue exists principally beneath or in those parts of the skin which have a dark tint, as, for example, the skin of the penis, the scrotum, and nipple. If, in addition to what we have already stated, it be recollected that the skin in its whole extent, independently of any cutaneous muscle, manifests a certain degree of contractility,—a phenomenon which cannot be owing to the admixture of muscular fibres in its tissue,—it will appear very probable that all the parts which we have mentioned,—the scrotum, skin of the penis and nipple,—owe their contractility to a contractile cellular tissue, which, in the structure of its primitive fibres, does not differ from ordinary cellular tissue. The similarity of the chemical properties of the dartos, and its difference in chemical composition from muscular fibre, strengthen this opinion; for M. Jordan has shown that the dartos is partially converted into gelatin by three hours' boiling; and that its solution in acetic acid, like that of cel-

lular membrane and all tissues which yield gelatin, is not precipitated, nor rendered turbid by ferrocyanide of potassium.

M. Jordan has likewise instituted some experiments relative to the nature of the contractile property of the dartos. The stimulus which most usually excites its contraction is cold; warmth relaxes it; and galvanism does not affect it: which fact is the more interesting, as it affords a means of distinguishing the contractility of cellular tissue from that of muscular fibre. The dartos has no share in producing the retraction of the testis towards the abdominal ring; this is effected solely by the cremaster. In animals in which the scrotum has no folds or rugæ, as in rabbits and dogs, M. Jordan found the dartos replaced by ordinary cellular tissue; while, on the contrary, in the ram, which has a very strongly though irregularly wrinkled scrotum, the dartos is very much developed. The scrotum of the ram became contracted and wrinkled under the application of cold water; but the cremaster at the same time contracted suddenly, drawing the testes upwards, and leaving the lower part of the scrotum, which contracted more slowly, empty. When the application of the cold water was desisted from, the scrotum as it recovered its warmth gradually relaxed, and its rugæ became unfolded; while, long before that had taken place, the testes had descended again as quickly as they had been retracted. The action of a galvanic battery of sixty-five pairs of plates, the wires being applied to the inner surface of the scrotum, had no influence on its contractility; while the testes were instantaneously drawn up by the contraction of the cremaster. The mode in which the shortening of the fibres of the contractile tissues, which we have been considering, is effected, is probably their inflexion into waving lines by the reciprocal attraction of aliquot parts of the fibres.

c. Of the elastic and contractile tissue of arteries.

It has been already shown, at page 202, from the results of galvanic experiments as well as from the real properties of the elastic coat of arteries, that this tissue does not possess muscular contractility. The yellow fibres which compose it are of the same class as those of all other elastic yellow membranes and ligaments, such as the ligamentum nuchæ of mammalia, the ligamenta flava of the vertebræ, the yellow ligaments of the larynx, the yellow fibres of the membranous part of the trachea and bronchi, the elastic ligament of the wing of birds, the elastic ligaments of the last phalanx of the toes in feline animals, &c. The elastic tissues are distinguished from all other tissues, not only by their yellow colour, but more especially by the character of their fibres, which, unlike all other known animal fibres, have been observed by

Lauth* and Schwann† to divide and anastomose (plate ii. fig. 6). In chemical properties the elastic tissues resemble the cellular and other tissues which yield gelatin by boiling, and of which the solution in acetic acid is not precipitated by ferrocyanide of potassium. (See Appendix to the Chapter on Nutrition.) Eulenberg‡ has recently discovered that, after long-continued (many days') boiling, they give out some gelatin, which differs, however, from the ordinary gelatin, being more like the "chondrin" which I have remarked to be afforded by cartilages and the cornea in boiling. The elasticity of the middle coat of arteries, the influence of which on the circulation of the blood has been described at page 199 et seq. is preserved for many years in alcohol. A portion of the aorta of a young whale, which I have received from my friend Professor Eschricht, is still highly elastic, although it has been several years in alcohol. Thin laminæ cut from it, are found, when extended, to have the same elasticity as caoutchouc. All elastic tissue retains its elasticity in the same way; this I have ascertained by experiment on all the elastic ligaments above-mentioned, after they had been kept in alcohol. In fact, the contractility of the fibrous coat of arteries is physical elasticity, not a vital property; it is exerted only after previous distension; for example, after the distension of the arteries by the blood impelled into them by the heart's contraction. Dr. Parry and Tiedemann have ascribed to arteries, in addition to their elasticity, a vital tonicity,— "tonus," a power of contracting, which does not essentially aid the rhythmic motion of the blood, but which is seen to be exerted in arteries which are laid bare, giving rise to a gradual narrowing of them: by virtue of this contractility, also, they supposed arteries to become narrowed at the time of death, but before all circulation has ceased, to a greater degree than mere elasticity would account for. It has been long known that cold water is of use in arresting hemorrhage from divided arteries. Dr. Schwann has succeeded in affording an explanation of this important fact by an interesting experiment. He has found that in transparent parts, in which the arteries are not fixed, and nearly free from any dense tissue around them, the application of cold water can be seen to excite a very slow vital contraction of the small arteries. His experiment is detailed at page 206: the mesentery of the *Rana bombina* is best adapted for it, being more easily spread out than the mesentery of the frog. Dr. Schwann's experiment was repeated so many times that the fact is placed beyond a doubt. I have myself verified it in the *Rana bombina*, or brown toad. The arteries which manifested this contractility measured about $\frac{1}{10}$ of a line in diameter. Dr. Schwann has observed a slight degree of this contractility in arteries of some-

* Müller's Archiv. 1835, p. 4.—L'Institut, Jun. 14, 1834.

† Eulenberg, de Telâ elasticâ. Berol. 1836.—Müller's Archiv. 1836, p. xxv.

‡ Loc. cit.

what larger size. We have already shown (at page 206) that the experiments to determine the contractility of arteries, which were instituted with chemical agents, were of no value. [Dr. Hastings* observed contraction of the small vessels in the web of the frog's foot, as the first effect of the application of ice; but, from the too protracted action of the cold, the vessels afterwards became dilated, and the motion of the blood retarded.] By the aid of a high magnifying power, delicate and indistinct transverse fibres can be distinguished in the parietes of the smallest arteries of the mesentery of the frog; and Dr. Schwann has discovered that even the capillary vessels in the mesentery of the frog have similar fibres,—a fact which decides the question as to capillaries having distinct parietes. Since these transverse fibres of the minute arteries have the same direction and arrangement as the fibres of the elastic coat of arteries generally, it is doubtful whether the vital contraction which is excited in small arteries by cold be due to these fibres,—whether the elastic tissue of arteries, which retains its elasticity for years when kept in spirit, possesses during life that vital contractility, or “tonus,” which is lost at the time of death; or whether the latter vital contractility of the smaller arteries is the property of unknown elements in their structure. We hesitate to ascribe the tone or vital contractility of arteries to their cellular sheath, because the small veins were observed by Dr. Schwann not to present that contractility. The “tone” of arteries differs from muscular contractility in not giving rise to sudden contractions, and also in not being distinctly excited by galvanism; cold being the stimulus by which most frequently the arteries, as well as the other contractile tissues which yield gelatin, are excited to contract.

d. Of the muscular tissue.

1. *Chemical properties of muscle.*—In respect of its chemical properties, muscle belongs to the class of animal tissues which cannot be made to yield gelatin by boiling, and of which the solution in acetic acid is precipitated by the red ferrocyanide of potassium: all the gelatin extracted from muscle by boiling is due to the cellular tissue which unites the muscular fasciculi. By these chemical characters muscular fibre may be easily distinguished from the different elastic tissues, including the elastic tissue of arteries, which yield gelatin in boiling, and of which the solution in acetic acid is not precipitated by ferrocyanide of potassium; whereas it is difficult and often impossible to distinguish chemically whether a body which belongs to the class of albuminous substances is muscle or not. Uncoagulated albumen may, it is true, be recog-

* Treatise on Inflammation, p. 55.

nised by its solubility in cold and lukewarm water, and by its property of being coagulated by a temperature of from 158° to 167° Fahr., by alcohol, and by metallic salts; uncoagulated fibrin may be known by its spontaneous coagulation when removed from the animal body; uncoagulated casein by its solubility in boiling as well as in cold water: but coagulated albumen and the coagulated fibrin of the blood and muscles cannot be distinguished from each other further than that fibrin decomposes the peroxide of hydrogen, while albumen has not that property. There is no chemical means of distinguishing the fibrin of the blood from that of muscle.

Those fibrous tissues, such as the fibrous tissue of the corpora cavernosa of the penis of the horse, which agree with muscle in their chemical characters, can be distinguished from it only by observing their vital properties; the red fibrous tissue of the penis does not contract when irritated (see the account of the erectile textures in vol. i.) If all muscular fibres were beaded or varicose, it would be easy to distinguish them by the aid of the microscope, but such is not the case. Even the contractility of the muscular fibres is not always sufficient to distinguish them; some fibrous tissues, as the dartos, have a slight degree of contractility; but these tissues are readily known by their chemical character of yielding gelatin.

The red colour of muscle has been ascribed to the presence of cruorin, the colouring matter of the blood; and the colour of muscle is, like that of the blood, rendered brighter by exposure to the air. But Dr. Schwann has once observed the naturally pale muscles of the carp become of a dark red during maceration for a short time in the cold in winter; a fact which seems opposed to the idea of the colouring matter of muscle and that of the blood being identical.

2. *Structure of muscle.*—The elementary parts of muscles are either beaded or cylindrical fibres, which are unbranched, and are arranged parallel to each other in fasciculi. According to Professor Krause, they are united together in the primitive fasciculi by a transparent tenacious fluid. The diameter of the primitive fasciculi, which contain from five to eight hundred fibres, is stated by Professor Krause, to be from $\frac{1}{240}$ to $\frac{1}{29}$ of an English line. The diameter of fasciculi taken from the pharynx of the human subject was found by Dr. Schwann to be from $\frac{1}{47}$ to $\frac{1}{40}$ of an English line. The primitive fasciculi are invested and connected together by cellular tissue, so as to form larger secondary fasciculi, which are again connected together by cellular membrane. Anatomists differ very much in their accounts of the form of the primitive fibrils. Some, as Professor Schultze, describe them to be simple, uniform filaments; others, as Bauer, Home, Milne Edwards, Prevost and Dumas, and Professor Krause, regard them as composed of globules; while others, again, describe them to be beaded threads. The first and last

of these descriptions, though apparently contradictory, are both correct, these two forms existing in different kinds of muscle.

1. *Muscles whose primitive fibres have a varicose or beaded structure, and whose primitive fasciculi have cross markings.* (Plate ii. fig. 7 and 8.)—It is this class of muscles that has been the most examined. It includes those muscles of voluntary as well as involuntary motion which are remarkable for their red colour; all the voluntary muscles, namely, except the expulsor muscle of the urinary bladder; and, among the involuntary muscles, the heart. All red muscles, however, are not of this kind; thus, the red muscular substance of the gizzard of the bird belongs, together with the muscular coat of the whole intestinal canal, to the second class of muscles. [According to Ficinus, the stomach of the bird contains varicose muscular fibres.*] The muscles of this first class are moreover not always red. The muscles of fishes are generally pale; the muscles of the gill-covers alone are frequently red; and a thin layer beneath the lateral line of the body in the carp is red. The red and pale muscles of fishes do not differ in the slightest respect in their structure; examined with the microscope, they are seen to be formed of fasciculi with cross markings and beaded primitive fibres. All the muscles of this class are remarkable, not only for the strength, but also for the rapidity of their contractions, which ensue instantaneously on the application of the stimulus.

The transverse striæ of the primitive fasciculi, seen when a portion of these muscles is examined with the microscope, follow each other very closely, are always quite parallel, and generally pass in a straight line across the fasciculus; occasionally, but rarely, they are a little curved. On the primitive fasciculi of the heart the transverse striæ are much less distinctly visible, but nevertheless exist, as Professor R. Wagner correctly remarks. The fasciculi occasionally present a waved outline. The primitive fibres present a regular succession of bead-like enlargements, which are somewhat darker than the very short constrictions which intervene between them. It is not correct, however, to assert that these fibres consist of a mere aggregation of globules, for there is a distinct continuation of the fibre intervening between the enlargements; and the opinion that they are formed by the aggregation of the nuclei of the blood particles is quite untenable, for their size has been found both by Professor R. Wagner† and myself to be in many animals different from that of the nuclei of the red particles of the blood (see p. 360). The diameter of the beaded muscular fibrils is stated by MM. Prevost and Dumas to be 0.00012 of a French inch [$\frac{1}{841}$ of an English line]. In the frog I found their diameter from $\frac{1}{461}$ to $\frac{1}{738}$; that of the most minute fibrils in the parrot, $\frac{1}{385}$ of an English line. Their size was found by Professor Wagner to be very nearly the same

* See page 851.

† Burdach's Physiologie, 5.

in all vertebrata, in insects and in the craw-fish, as well as in the heart of the *Helix pomatia*; namely, from $\frac{1}{738}$ to $\frac{1}{923}$ of an English line. Professor Krause estimates the size of the fibrils at from $\frac{1}{738}$ to $\frac{1}{978}$ of an English line. The red particles of the blood of the rabbit are five or six times larger than the primitive fibres of its muscles.

Dr. Schwann has applied himself during an entire winter to the microscopic examination of muscle; the following are the results at which he has arrived. The diameter of the primitive fasciculi varies from $\frac{1}{46}$ to $\frac{1}{40}$ of an English line. To obtain the primitive fibrils in an isolated state, the muscles should be macerated at a low temperature varying from 34° to 50° of Fahr. during a period of from eight to twenty-one days. If macerated at a higher temperature, they are converted into a pulp in which the original structure cannot be recognised; but even at the temperature above mentioned the maceration affects the muscles of different animals differently. Sometimes the transverse striæ disappear before the primitive fibres separate; sometimes the muscle divides in the direction of its length rather than into its primitive fibres, although the transverse striæ remain distinct. The fibres are most easily examined in the muscles of the rabbit. They are beaded filaments, presenting under the microscope a succession of dark points from $\frac{1}{1666}$ to $\frac{1}{1250}$ of an English line in breadth, separated by bright and somewhat narrower portions of the filament. The distance of the points from each other is not everywhere the same; it can be estimated very accurately by measuring the length of a portion of a fibre which contains a known number of points. Thus a portion of a fibre from the human pharynx, containing five of the dark points or enlargements, measured 0.0060 of a line: one of the enlargements, therefore, with the transparent narrow portion belonging to it, measured 0.0012 of a line; of which about 0.0004 was occupied by the dark enlargement, 0.0008 by the narrow part. The appearance of transverse striæ on the primitive fasciculi is produced by the dark points of the fibrils being arranged side by side in the fasciculus; this is proved by the following circumstances. 1. The distance of the striæ and that of the dark points of the fibrils from each other is exactly the same. 2. The primitive fibrils sometimes become spread out at the end of a fasciculus of macerated muscle, without their relative position in the longitudinal direction being altered. The transverse striæ are then still seen in these expanded parts of the fasciculus; they correspond exactly in their degree of separation from each other with the striæ of other parts of the fasciculus, but are here distinctly seen to be formed of dark points, not sufficiently approximated to constitute a continuous line. 3. Lastly, the relation of the fibrils in the longitudinal position is sometimes disturbed; and the primitive fasciculus then appears at the first view to be dotted, not marked with transverse striæ. On a more close

examination, however, it is seen that the dark points, when traced in the direction of the fibres, succeed each other at regular intervals, while in the transverse direction the series of points is irregularly interrupted.* The appearance of transverse striæ being produced by the dark points of the primitive fibres, it necessarily follows that the distance at which the striæ are separated from each other indicates the distance between the dark points of the fibres. In any single primitive muscular fasciculus the transverse striæ are all parallel; the dark points of all the primitive fibres of a fasciculus, therefore, are at equal distances. But the degree of separation of the transverse striæ may be very different in different fasciculi which lie close side by side with each other. This last circumstance is seen very remarkably in the muscles of the human pharynx. The space included by five transverse striæ of these muscles was in one fasciculus from 0.0065 to 0.0068; in another, from 0.0053 to 0.0056 of a line; in a third fasciculus the striæ were even much closer, so that they could not be counted. In a muscular fasciculus from the pharynx of another subject, the space occupied by five striæ was found by Dr. Schwann to be 0.0034; in another fasciculus, which lay quite close to the former, 0.0080 of a line. [According to Mr. Skey's observation, the distance of the striæ from each other is sometimes very different, even in the same fasciculus, at different parts.] The usual space occupied by five striæ in the voluntary muscles of the rabbit was from 0.0043 to 0.0046 of a line.

The limits to which this class of muscular fibres encroaches on the sphere of the organic muscles with uniform cylindrical fibres, has been already detailed at page 850.

[The primitive fasciculi are, as Mr. Skey has observed and figured, smaller in the foetus; their diameter being about one third of that which they have in adult age.]

* [In a paper in the Philosophical Transactions for 1837, Mr. Skey has given an account of the muscular fibre, which differs in some respects from the descriptions of previous anatomists. Mr. Skey believes the striæ of the fibres (primitive fasciculi of Müller) to be independent of the filaments (primitive fibrils); the beaded appearance of the latter is owing, he thinks, to indentations made upon them by the striæ. Mr. Skey believes also that the fibres are really tubes, containing in their interior a semi-transparent amorphous substance, around which the filaments are arranged. The principal arguments which he adduces in support of this opinion are: — first, that the extremity of a divided fibre sometimes presents the appearance of a jagged circle terminating an apparently hollow tube; — second, that the fibre is frequently elongated to a point, up to the extremity of which the external surface presents the transverse striæ; — third, that when a fibre is separated into its filaments at its extremity, he sees no filaments projecting from its centre, but only from its borders; — fourth, that when dried on glass, the dark outline only of the fibre remains apparent, the centre is obliterated; — fifth, that the separation of a few filaments from the surface of the fibre never exposes other filaments beneath them.]

The beaded muscular fibres with primitive fasciculi marked with transverse striæ are not confined to vertebrate animals. The voluntary muscles of insects, for example, are wholly constituted by them. Each primitive fasciculus has a very delicate sheath, which can often be perceived forming a transparent border to the fasciculus.

Professor R. Wagner* has examined the structure of the muscles in many of the lower animals. He met with muscles of which the primitive fasciculi presented cross striæ, in insects, crustacea, cirropods, and arachnida.

2. *Muscles with uniformly cylindrical primitive fibres and primitive fasciculi devoid of transverse striæ.* (Plate ii. fig. 9.)—These fibres are found to compose the muscular coat of the whole intestinal canal of the higher animals from the œsophagus to the anus.

This is the more remarkable, as the muscles of the pharynx belong to the former class,—the muscles with beaded fibres. The diameter of the primitive muscular fibre from the large intestine of the human subject was found by Dr. Schwann to be 0·0007, 0·0011, and 0·0013; in the mean, about $\frac{1}{1000}$ of an English line. Their border or outline was quite smooth and even. In the uterus of the human subject, in the pregnant uterus of the rabbit, and in the urinary bladder, Schwann could detect no fasciculi marked with transverse striæ. From the human iris, and that of the rabbit, he was unable to obtain any isolated fibres; although he, as well as M. Lauth,† perceived in the iris a distinct appearance of fibres, which had a concentric arrangement near the pupillar margin, and a radiate disposition in the periphery. The circular fibres in the iris of the ox consist, according to Lauth, of fibrils collected into fasciculi which interlace one with another; M. Lauth perceived no other than the circular fibres. Dr. Schwann was able by traction to distinguish very easily the separate fibres of the iris of the pig without any previous maceration. They were very minute, $\frac{1}{5000}$ to $\frac{1}{3333}$ of an English line in diameter, and perfectly cylindrical, not beaded.‡

The muscular fibres of this second class occur among the invertebrata, according to Professor Wagner, in all mollusca in which he has examined the muscles, (in cephalopods, gasteropods, testaceous acephala, and ascidiæ,) and likewise in the echinodermata.¶

* Müller's Archiv. 1835, p. 318.

† L'Institut, No. 57. 70. 73. 1834.

‡ [The muscular filaments of organic life in the human subject are not cylindrical, but flat bands, in which, at intervals, small bodies like the nuclei of cells are contained. These filaments are, moreover, not regularly aggregated together into cylindrical fibres, like those of animal life.]

¶ For the account of the developement of muscles, and of Valentin's labours on that subject, see page 384. For a detail of the physical properties of muscle, we refer to Haller's Elementa Physiol. lib. xi. s. 2, § 2, and Weber's Anat. i. 396.

2. *Of the vital properties of muscle.*

In addition to the vital properties common to all animal tissues, muscles possess sensibility and contractility. The sensibility of muscles is seated in the sensitive nervous fibres distributed to them, and not in the muscular fibrils themselves: the contractility is the essential property of muscles, which manifest it under the influence of every stimulus; while other organs, not muscular, are by the same stimuli excited to the manifestation of other properties, such as sensation, secretion, &c. Muscles possess but slight sensibility to external impressions, such as cuts and punctures. A needle passed through the skin may be carried deeply into the substance of a muscle without pain being produced; the heart laid bare has been observed to possess a very slight degree of sensibility. The muscles, however, are endowed with a very delicate sense of their internal condition; or rather, their nerves communicate accurately to the sensorium a knowledge of the states induced in them by their contraction: by virtue of this property we are not only made conscious of the sensations of fatigue and cramp in muscles, but acquire through muscular action a knowledge of the distance of bodies and their relation to each other, and are also enabled to estimate and compare their weight and resistance. This muscular sense cannot, however, be seated in the same nervous fibrils which excite the motions. If, in a frog, the posterior roots of the nerves for the hinder extremity are divided, the anterior roots being left uninjured, all trace of sensibility is lost in the muscles as well as in the skin of the leg and foot, while the power of voluntary motion continues perfect. A portion of the leg may be cut off without exciting any motion of the animal. On the other hand, by dividing the anterior roots only, the power of motion may be taken away and the sensibility left intact.

Muscles are thrown into action by any stimulus applied to themselves or to their motor nerves. All stimuli, as mechanical or chemical influences, cold, heat, or electricity, produce the same effect. They all excite contraction of the muscles even when applied to their nerves. Acids act more readily when applied to the muscles themselves than when applied to the nerves; it is not, however, as we remarked at page 615, a constant rule that acids excite no muscular contractions, when they act on the nerves alone. Dr. Bischoff and Professor Windischmann have at all events frequently seen muscular contraction produced in the latter case. The property which muscles possess of contracting under the influence of any stimulus was made the subject of special study by Haller,* who called it "irritability," in contradistinction to the sensibility of nerves. There are, however, so

* Deux Mémoires sur les parties sensibles et irritables. Lausanne, 1756.

many hypothetical notions and false ideas connected with the name "irritability" in this sense, that it figures better in the history of medicine than in discussions on physiology itself.

Muscles retain their property of contracting under the influence of stimuli applied to them or to their nerves for some time after death; the period varying with the degree of complexity of the organisation of the animal. The more complex the structure of the body, the more dependent are its different parts on each other, and the sooner are the vital properties of individual tissues lost after the vital action of the system has ceased. The contractility of muscles is preserved for a longer time by cold-blooded than by warm-blooded vertebrata. The contractility of the heart is retained for several hours in fishes, reptiles, and amphibia; and in the frog the other muscles also retain their contractility for several hours, particularly in the colder season of the year: a tortoise for a week after decapitation presents some contractility in its muscles. In higher animals the muscular contractility is seldom retained more than one or two hours after death; there are instances, however, in which it is not lost for many hours, an example of which is afforded by the cutaneous muscle of the hedgehog. Nysten,* in his experiments on the bodies of executed criminals who were previously in good health, found that the different muscles lost their contractile property in the following order: the left ventricle of the heart first, the intestinal canal at the end of forty-five or fifty-five minutes, the urinary bladder nearly at the same time, the right ventricle of the heart after the lapse of an hour, the œsophagus at the expiration of one hour and a half, the iris fifteen minutes later, the muscles of animal life still later, and last of all the auricles of the heart; the right auricle being the part which retained its contractility longest, in one instance contracting under the influence of galvanism sixteen hours and a half after death. In birds the muscular contractility is lost sooner than in mammalia, — namely, in from thirty or forty minutes to an hour after death. The muscles of young animals retain their contractility in general longer than those of adults. In new-born kittens Nysten excited contraction in the muscles by the application of stimuli three hours and forty-five minutes after death; and at the end of six hours and a half the right auricle was still irritable. A general conclusion which may be drawn from the preceding observation is, that the greater the influence of respiration on the animal, and the greater the necessity of aerated blood to the system, the shorter is the time of duration of the irritability in the muscles after death.

There are many substances which have the property of deadening the muscular irritability. The muscles of animals killed by immersion

* Rech. de Physiol. et de Chim. Path. 321.

in carbonic acid gas, hydrogen, carbonic oxide, or by the vapours of sulphur, contract very feebly, or not at all, when stimulated; while in the atmosphere, or oxygen, muscles retain their contractility much longer.* The action of pure water on muscles for any length of time diminishes their irritability in a remarkable degree. This was first observed by Nasse, and has been recently confirmed by Dr. Stannius. The legs of frogs freed from the skin, and laid for a short time in water, are no longer adapted for delicate experiments on the excitability of nerves and muscles.† Narcotic substances, applied directly to the muscles, destroy their irritability; applied to the nerves, they deprive the nerve, at the point which they have acted on, of the property of exciting muscles to contraction; but, between that point and the muscle, the motor power of the nerve is preserved. When animals are killed by the introduction of narcotic poisons into the blood, the irritability is not affected in so great a degree as by the local application of the narcotic in a concentrated state; muscular contractions can be excited by irritating the muscles or nerves for several hours after death in frogs poisoned by narcotics. Substances which have a decomposing chemical action on animal matters,—the caustic alkalies, concentrated acids, and chlorine, for example,—annihilate the irritability of muscles instantaneously at the point which they touch. There are no bodies known to have the property of heightening the irritability of muscles.

Muscular contractility is subject to the general laws of animal excitability. Muscles become feeble if seldom excited to action; and a great exertion of their contractile power always induces temporary exhaustion of it. Excitement and rest are, therefore, equally necessary for the maintenance and increase of the muscular power. The excitement seems to cause the organic processes necessary for the nutrition and formation of muscular tissue to go on more quickly during the succeeding state of rest. Temporary exhaustion is, however, a necessary consequence of the state of activity, action and excitement being themselves always attended with changes of composition of the tissue (see p. 52, et seq.) These facts may be demonstrated, to a certain extent, in the muscles even of a dead frog. The contractions of the muscles of the frog, if at first feeble, may be rendered more energetic by moderate and occasional applications of the galvanic stimulus; but the stimulus, being too frequently applied, exhausts the power of the muscles rapidly; and when the repeated action of the stimulus has caused the contractions to become feeble, rest often restores, in some measure, the irritability.

The state of contraction of muscles, which renders them firmer and harder, is alone the active condition; in their more elongated state they

* Tiedemann's *Physiol.* i. p. 551.—Nysten, *loc. cit.* p. 323.

† Hecker's *Annal.* Dec. 1832.

are relaxed. There is no fact to justify the supposition that muscles possess a power of active expansion. The opinion that the heart has such a power has been refuted by Oesterreicher (see p. 173). The living muscles must not, however, be supposed to be at any time in a state of complete relaxation. They are constantly, even in the state of rest, subject to the influence of the nervous principle; this is seen in the retraction of divided muscles, in the slight tremors of muscles laid bare during life, and in the distortion of the features, and drawing of the tongue to one side, in hemiplegia.

If a muscle is observed at the moment of its contraction, it is seen to become thicker in the same proportion as it is shortened; and very often its fasciculi are seen to be for an instant bent into waving lines. The circumstance of the muscles becoming firmer in the state of contraction might naturally induce the conjecture that their substance becomes condensed so as to occupy a smaller volume; although, without this being the case, the mere strength of the attraction of certain parts of the muscle towards each other would explain the increased firmness. I will pass over the less perfect observations of Glisson and Swammerdam,* and will detail merely the more accurate experiments of later date. The muscular part which is to be experimented upon, is introduced into a cylinder filled with water, which is at one extremity elongated into a fine tube, in which the height of the water is noticed at the moment of the contraction of the muscles excited by galvanism. In such experiments, Bazzellotti, Mayo, and Prevost and Dumas, who employed muscular parts of small volume, observed no change in the level of the fluid; while, by Professors Gruithuisen and Ermann,† a fall of the fluid was perceived. The change in the level of the fluid, observed by M. Ermann, was very slight. He introduced into a glass vessel the hinder half of an eel without the viscera, one wire of a galvanic battery being connected with the spinal cord, and another with the muscles of the body. The vessel was then filled with water to such an extent that a narrow glass tube, in which the apparatus terminated superiorly, was partly filled. The wires being connected with the poles of a galvanic battery, the water in the glass tube fell about four or five lines each time that the circle was closed and contraction of the muscles produced, and rose again when the circle was interrupted. The condensation of the muscular substance during its contraction is, therefore, far too slight to aid us in explaining the phenomena of muscular contraction. And it is possible that the condensation which took place in these experiments was owing to the air contained in the divided vessels being pressed out of them by their contraction; it might certainly be thus completely accounted for. When the experiment of M. Ermann is repeated, the portion of eel

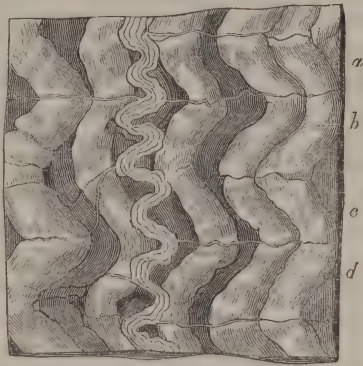
* Haller's *Element. lib. xi. s. 2. § 22.*

† Gilbert's *Annal.* 40.

should be prepared under water, and introduced into the tube without coming into contact with the air.

The modes in which the muscles could become shorter during their contraction are threefold. 1. The zigzag inflexion of the muscular fasciculi. This can be seen with the naked eye in muscles during contraction, but may be more accurately observed with the aid of a lens. The fasciculi of muscular fibres are thrown into zigzag inflexions (fig. 56). MM. Prevost and Dumas*

Fig. 56.



have in particular studied this phenomenon. They regard each muscular fibre as composed of a number of short lines (*a, b, c, d,*) disposed in a series, which can be approximated to each other. The [apparent] length of these short lines, in the muscle of the leg of a frog, [under a microscope of low power,] was from ten to twelve millim.;† the distance between the angles of inflexion of the same side, from sixteen to seventeen millim.; the space occupied by sixteen such inflected portions, when the fibre was straight, 172·5 millim.; and the space which they occupied in the contracted or bent state of the fibre, 130 millim. The degree in which the fibre became shortened was, therefore, $\frac{23}{100}$ of its length. Prevost and Dumas, moreover, measured the degree of shortening of the entire mass of the same muscle, and found it amount to $\frac{27}{100}$ of its length. Since this and the foregoing measurements nearly agree, MM. Prevost and Dumas concluded that the shortening of the muscle during its contraction was due to the above described angular inflexions of the muscular fibres. It is, however, from many reasons probable that the angular inflexion of the fibres observed by these physiologists, and so easily seen even with the naked eye, is not the sole, and perhaps not even the most essential cause of the shortening of the muscles.‡

* Journ. de Physiol. iii. p. 311.

† [A millimetre is 0·03937, or nearly $\frac{1}{25}$ of an English inch.]

‡ [Prof. Owen and Dr. A. Thompson doubt the accuracy of the observation, that muscular fibres, at the moment of contraction, are thrown from a straight to a zigzag line. Prof. Owen was led to doubt it, "from observing the contraction of the muscular fibres in small filariæ, (such as commonly infest the abdominal cavity of the cod,) and more especially from observing the contraction of the retractor muscles of a species of vesicularia." * * " Here each separate fibre of the retractor muscle is seen with great distinctness, and is characterized by a single knot or swelling in the middle. In the act of retracting the tentacles, the fibres become shorter and thicker, especially at

2. M. Lauth has made some important observations with regard to muscular contraction.* Exposing a muscle, which still preserved its irritability, to the action of galvanism under the microscope, he perceived that its contraction was effected in two ways. When the muscle contracted most forcibly, its whole secondary fibre or primitive fasciculus was thrown into angular inflexions; a more feeble galvanic stimulus caused a shortening of the entire secondary fibre, without any zigzag inflexion. In the latter case, the surface of the secondary fibres, or primitive fasciculi, is not smooth, but presents, in its whole extent, transverse rugæ (rides), which are also visible in the fibres while bent into zigzag lines, but are quite independent of that zigzag inflexion. It is probable, therefore, says M. Lauth, that this slighter degree of shortening is due to the contraction of the primitive fibres; and this contraction he supposes to be effected by the approximation of globules composing the fibres. In the primitive muscular fasciculi of insects I have observed a kind of cross marking, which is different from the ordinary close transverse striæ; it is seen most distinctly in those muscular fasciculi of insects which have lain in spirit, but is also frequently to be seen here and there in the fresh muscles. These (secondary) cross striæ are much more distant from each other than the primitive transverse striæ, but they occur at regular intervals; and the primitive fasciculus of muscle macerated in spirit often appears as if regularly articulated, and in such muscle the primitive fasciculi easily break at these points. The space between two of the secondary transverse striæ measures somewhat less than half the breadth of the primitive fasciculus. Five of the spaces measured $\frac{1}{100}$ of an English line; each space, therefore, would be $\frac{1}{500}$ of an English line. The secondary cross striæ were generally straight, sometimes rather oblique or curved, but always parallel to each other for a considerable extent of the fasciculi. In the muscles of insects which had

the central knot, but do not fall out of the straight line." (This mode of contraction of the muscular fibres of polypifera has also been observed by Dr. A. Farre, Philos. Transact. 1837, pp. 394 and 396.) "After the retraction has been effected, the fibres fall into a wavy or zigzag position; but this is characteristic of their state of relaxation under the circumstances which bring their two attached extremities nearer each other. In like manner, in the parallel longitudinal fibres of the filariæ, it is most evident that at the moment of contraction they become shorter and thicker, but do not alter their rectilinear position until the action has ceased, when they fall, like the parallel nervous chord, into zigzag folds, which continue until effaced by the restoration of the part to its usual length through the action of the exterior transverse fibres." Dr. Allen Thompson, on repeating the experiment of Hales and Prevost on the frog, "observed single fibres continuing in contraction, and being simply shortened, and not falling into the zigzag plicæ: and he was led to suspect, from this and other circumstances, that the zigzag arrangement was not produced until after the act of contraction had ceased." (Hunter's Works, vol. iv. with notes, by R. Owen, F. R. S. 1837.)]

* L'Institut, No. 57. 70. 73. 1834.—Müller's Archiv. 1835, p. 4.

been kept in spirit the fasciculi were distinctly constricted at these secondary cross striæ, and enlarged in their intervals; the constricted and tumid parts appearing dark or bright according to the variation of the light. Sometimes the constriction appeared light, the tumid part dark; sometimes, the focus of the microscope being slightly altered, the constricted part appeared dark. The light portion of the transverse constriction measured $\frac{1}{14.29}$ of an English line; the dark intervening portion, $\frac{1}{76.9}$. These constrictions of the primitive fasciculi are certainly not due to the mere wrinkling of their sheath; for the sheath can be distinguished forming a transparent border to the fasciculus, and the constriction is seen to affect, not it only, but the muscular substance of the fasciculus formed of primitive fibres with primitive transverse striæ. The muscular fasciculi of insects being so similar in the form of their fibres and in the existence of the primitive transverse striæ to those of the higher animals, the appearance of secondary constrictions on the former is a circumstance of importance with reference to the explanation of muscular contraction; and the fact of the secondary transverse striæ or constrictions being present only in parts, renders it still more probable that they are due to the contraction of the primitive fasciculi. A fasciculus of fibres can, it is plain, become shorter in two ways; either by the whole fasciculus being bent alternately in opposite directions, the fibres in the intervals of the flexure remaining parallel to each other, which mode of shortening takes place visibly in the larger muscular fasciculi, or by the fibres of the fasciculus spreading out in the intervals of transverse lines which divide the fasciculus into aliquot parts. The latter mode of contraction, very probably, takes place, together with the first, in the muscles of insects, and perhaps also in those of the higher animals.

3. It is possible that the muscular fibres of the second class (those of the organic parts of the body) contract both in the first and the second mode simultaneously; but there is a third manner in which the muscular fibres of the animal system may shorten themselves,—namely, by the approximation of the bead-like enlargements, and the contraction of the interspaces between these enlargements of the primitive fibres. Such a mode of contraction can neither be demonstrated, nor proved not to take place. The absence of the beaded enlargements in an entire class of muscles would render any theory of muscular contraction defective, which was based on them alone. Still, the approximation of the globules of the primitive fibre may very possibly take place in the muscles of animal life, in addition to the other modes of contraction which are seen in the primitive and secondary fasciculi; and there are, in fact, some reasons for believing that in them it actually does occur. These reasons are,—first, the circumstance that the beaded enlargements of the primitive fibres are not necessary either to the contraction of the primitive fasci-

culi into belly-like portions, or to their zig-zag inflexion; for a whole series of the bead-like enlargements intervene between the flexures:—secondly, the positive argument that, according to Dr. Schwann's observations on contiguous fasciculi, the enlargements of the primitive fibres and the corresponding transverse striæ of the fasciculi are not always separated by equal intervals. This is all that can be said in support of the hypothesis of the approximation of the globular enlargements of the primitive fibres. There are, however, two ways in which such an action might be supposed to be effected,—namely, by the reciprocal attraction of the globules towards each other; or, supposing the primitive fibres to be hollow, by the distension of their varicose enlargements with a fluid so as to increase their size at the expense of the intervening parts of the fibre. It would be useless and rash to hazard any more remarks on this question. It is impossible, in the present imperfect state of our instruments, to determine whether such excessively delicate threads as the primitive muscular fibrils are solid or hollow; and an account of the opinions and bold hypotheses of the earlier anatomists regarding them would be misplaced in this work.*

The rigidity of muscles after death, rigor mortis.†—This phenomenon is due to a particular state of the muscles, which ensues at a certain period after death, giving rise to stiffness of the limbs, and after a time ceases. The rigidity affects the neck and lower jaw first, according to M. Sommer; next, the upper extremities, extending from above downwards; and lastly, reaches the lower limbs: in some instances it begins in the lower extremities, or affects them simultaneously with the upper extremities. Out of two hundred cases, M. Sommer only observed one in which the rigidity did not commence in the neck.

When the limbs have become rigid, the muscles, flexors as well as extensors, feel firmer. M. Sommer states that a slight motion takes place when the muscles become rigid; he affirms that Nysten was incorrect in stating that the position of the limbs always remains unchanged. The lower jaw, he says, though it be separated from the upper jaw at the time of death, becomes afterwards firmly drawn up towards it. The extremities also become more strongly flexed; thus the thumb is drawn towards the palm, and even the fore-arm is a little bent on the arm. If the rigidity of any part after it is fully developed be forcibly overcome, it is not reproduced; but if the part be not yet in its complete state of rigidity, forcibly flexing it will not prevent its again becoming stiff. The rigidity usually ceases as it began; first at

* See Haller's *Elementa*, lib. xi. s. 3.

† Nysten, *Rech. de Physiol. et de Chim. Pathol.*—Guentz, *der Leichnam des Menschen*, Leipz. 1827.—Burdach, *Physiol.* Bd. 3.—Nicolai, *Rust's Magazin*, 34. 2.—A. G. Sommer, *Diss. de signis mortem hominis absolutam indicantibus*. Pars 2. Havniæ, 1833. 8.

the head, then in the upper extremities, and lastly, in the lower extremities. The rigidity, according to Sommer, never commences earlier than ten minutes, and never later than seven hours, after death. Both Nysten and Sommer state that its duration is greater in proportion to the lateness of its accession. If the muscular energy was undiminished at the period of death, as in men killed by asphyxia, the rigidity of the limbs ensues later and continues longer; while, on the contrary, in bodies of persons who have died of acute diseases attended with great depression of the vital powers, it comes on more rapidly; after death from typhus, for example, M. Sommer has sometimes known it to be developed in fifteen or twenty minutes. In the bodies of individuals exhausted by chronic diseases, the same fact is observed. After sudden death from acute diseases, the rigid state of the limbs continues for a long time, even though it be rapidly developed. Hunter and Himly have remarked that, in the bodies of persons killed by lightning, no rigidity of the muscles takes place; M. Sommer, however, states that, in a dog killed by an electric shock, the phenomenon ensued at the ordinary period after death. The remark of Orfila, also, that after death from the vapour of charcoal the limbs do not become rigid till after a longer period than usual, was found by M. Sommer to be incorrect: he remarks that, if in some cases the rigidity of the limbs appears to be late in being developed, this is owing not so much to the mode of death, as to a state of apparent death preceding the real cessation of life. The assertion that the muscles do not become rigid after poisoning with narcotic substances, is also contradicted by the experiments both of Nysten and Sommer on animals. Nysten had made the remark that the rigidity is equally intense in muscles paralysed by hemiplegia: this is confirmed by Sommer, with the proviso that the paralysis must not have been attended with any considerable modification of nutrition, nor with serous effusion into the muscles; for, in such a case, Sommer has once observed an entire absence of rigidity on the paralysed side. Nysten remarked that death from tetanus was attended with or quickly followed by a cessation of the spasms, and that the body then remained in a flexible state for some hours before the rigidity of the corpse ensued: in one case observed by Sommer, however, the tetanic cramp of the muscles of the jaw passed immediately into the rigidity of death. In new-born infants and old people, the rigidity of the limbs generally comes on earlier, is less intense, and lasts a shorter time. Sommer observed that, contrary to the statement of Nysten, the body in many instances became rigid before it was completely cold, and sometimes even while still warm. The body becomes rigid after death in water as well as in the air; but in water of the temperature of 32° to 66° Fahr. the rigidity is greater and of longer duration than in air of the same temperature. With reference to the question of the influence of

the brain and spinal cord on the production of the phenomenon which we are considering, Sommer confirms Nysten's observations as to the fact that destruction of the central organs of the nervous system in animals has no influence on the developement, degree, or duration of the subsequent rigidity of the body.

The cause of the rigidity is, according to Nysten, seated in the muscles; for the limbs still remain stiff, though the fasciæ and even the lateral ligaments of the joints be divided, but become flexible as soon as the muscles are cut through. This statement is confirmed by Sommer, who adds that, although the limb recovers its mobility from the division of the muscles, still the divided muscles themselves remain firm and rigid,—a fact previously noticed by Rudolphi. Nysten referred the rigidity of dead bodies to the organic contractility of the muscular fibres. Of his grounds for this opinion, the most important is, that when the rigidity affects a limb which is completely flexed, the flexor muscles are found to be in exactly the same condition as during their voluntary contraction; they are not relaxed, but shortened, and thicker than in the ordinary condition. Sommer, however, does not admit the correctness of this statement. If one arm of a corpse be, at the time that it becomes rigid, in the state of flexion, the other extended, the biceps of the arm thus extended will, he says, become rigid as well as the other, though its rigidity does not resemble the state of voluntary contraction. With reference to this question, it is important to know whether the muscles, when rigid, still present signs of contractility under the influence of stimuli. Nysten had, in some instances, observed that a slight degree of contractility was preserved. Sommer found that generally the application of stimuli excited no contraction; sometimes distinct contractions were produced, without, however, influencing the position of the limbs. It is generally found, that the quicker the muscles lose their irritability, the sooner do they become rigid; thus the rigidity affects them soonest in birds: in reptiles and amphibia, in which the muscles retain their irritability for a long period, they are late in becoming rigid, and remain so a shorter time. Sommer ascribes the rigidity to a physical contractility of the muscles, distinct from their organic contractility or irritability; for it does not take place, he remarks, until all the vital phenomena have become faint; and a similar contraction of a physical nature is seen after death in parts not muscular,—in the skin, in cellular tissue, in the fasciæ and ligaments. Orfila, Beclard, and Treviranus believed the phenomenon to be dependent on the coagulation of the blood. But M. Sommer thinks this opinion incorrect, since the body sometimes becomes very rigid when the blood has not coagulated, or but imperfectly; thus, in persons drowned, the rigidity of the limbs is very great, while the blood is often fluid; and the same is the case in men and animals killed by prussic acid. Sommer, however, admits the

resemblance of the two phenomena,—that coagulation is the death of the blood, the state of rigidity the death of the muscles. I regard the correctness of the explanation of the phenomenon by the coagulation of the blood in the small vessels as by no means disproved. The coagulation of the blood and lymph in the small blood-vessels and lymphatics must render the muscles more firm; and it is a question only whether this increased cohesion of the muscles would alone suffice to explain the phenomena. This cannot be proved; but the hypothesis is so far tenable as it affords an explanation of the subsequent solution of the rigidity. The blood and lymph in coagulating become a solid, gelatinous mass; but after a time, and frequently after a considerable interval, the coagulum of fibrin, which includes the more fluid parts, contracts so as to expel the serum. As soon as this has taken place in the coagulated blood and lymph of the small vessels, the cohesion of all the textures must be diminished. The coagulation of the blood, and the coagulation of the adipose matter after death, in warm-blooded animals, both render the textures more firm; but, while the firmness produced by the coagulated blood is lost again, the adipose substance retains its coagulated condition. I do not, however, by any means affirm that the explanation of the post-mortem rigidity by the coagulation of the blood is correct, or that it is the one which I adopt. I merely say, that, in the present state of our knowledge, it seems to me impossible to prove either its correctness or its fallacy. Should it at a future time be determined that the rigidity of the corpse is owing to a physical contractile property of the muscular fibres exerted at the time of the loss of their vitality, and ceasing with their decomposition, the phenomenon would be more analogous to the physical contraction of the fibrinous coagulum to a smaller and denser substance.

CHAPTER IV.

OF THE CAUSES OF MOTION IN ANIMALS.

IN an inquiry into the causes on which the motions of the solid textures of organic bodies depend, it is necessary in the first place to distinguish between the motions of parts devoid of nerves, and those which are consequent on a reciprocal action exerted between the contractile tissue and the nervous system. Motions of the first kind are presented by plants, and perhaps also by some parts of animals which are not muscular. The first traces of organic contractility in its simplest condition are observed in the *Oscillatoria*,—those simple vegetable filaments which consist of a tube filled with granules closely arranged in a linear order. These granules are at certain periods expelled from the tube, which does not thereby lose its contractility. On account of the sim-

plicity of their structure, the motions of these vegetables are of great importance with reference to the theory of motion in organic bodies. I have seen them under the microscope at the house of Professor Meyen. When the filaments begin to move, they slowly, and with scarcely perceptible motion, bend to one side, and then after some time bend back again, and become curved in the opposite direction, the granules in the interior of the tube remaining all the time quite motionless. Since these movements take place independently of any attraction exerted by neighbouring filaments, and since no circulation or motion of sap can be detected in the interior of the filaments, we can conceive no other explanation of the phenomenon than that the component particles of the parietes of the tube, in consequence of an exaltation of vitality alternately on the two sides of the filament or tube, attract each other at those parts, so as to become condensed, or that the sides of the tube alternately at different parts attract and imbibe water, so as to become swollen with it. The idea of the walls of the tube becoming contracted by a wrinkling (*Kräuselung*) is quite incompatible with the appearance presented by the plant in motion. The spontaneous rhythmic motions of the leaves of the *Hedysarum gyrans*, which occur independently of external excitement, present us with the same phenomenon in a more highly developed vegetable.

The time has not arrived for inquiring into the causes of the ciliary motion. We do not even know by what mechanism it is produced. In its great independence of the influence of the nervous system it resembles the motions of plants. The motions of cellular tissue, or the contractile animal tissue which yields gelatin,—motions which are readily produced by the action of stimuli, particularly cold, heat, and mechanical influences, on the tissue itself,—in some degree resemble those of plants and the cilia, which are independent of the influence of the nervous system. They resemble the motions of plants in another circumstance also, namely, in not being perceptibly excited by electricity. The motions of the cellular and allied contractile tissues are not, however, entirely withdrawn from the influence of the nerves. The contraction of the skin and dartos is excited not only by external stimuli, but frequently also by causes seated in the nervous system. The dartos is frequently contracted, and the scrotum thrown into wrinkles, under circumstances in which the presence of nervous excitement in the genital organs cannot be doubted, and where the cremaster is at the same time in action; the contractility of the skin also is frequently manifested under the influence of affections of the nervous system quite as manifest,—for example, it accompanies rigors (where there is both sensation and motion at the same time produced). Since, however, in the case of these motions, the nature of the influence exerted by the nervous system is not easily ascertained, our whole attention must be directed to the muscles,

in which a most marked reciprocal action between the contractile tissue and the nerves is manifest.

The contractile property of the muscles is intimately dependent on two different influences,—the influence of the blood, and that of the nerves.

1. *Influence of the blood.*—Stenson first pointed out that muscles lose their power of motion when the current of blood (that is, of arterial blood) towards them is obstructed. This phenomenon is sometimes observed when a ligature is applied to a large arterial trunk in the human subject; the power of moving the muscles under the influence of the will is either partially or wholly lost, until the collateral circulation is developed. This fact has been confirmed by Arnemann, Bichât, and Emmert.* Segalas† also has observed that, when the abdominal aorta is tied in animals, the hind-legs are rendered so weak, that after eight or ten minutes they can scarcely be dragged along. Whether the principal influence of the blood consist in its maintaining the contractility of the muscles, or in its enabling the nerves to convey the influence of the will, has not been investigated. Treviranus argued, in opposition to M. Percy, that the blood is shown to be necessary to the muscles, since the division of the great arteries of the limbs into numerous anastomosing branches in some animals which use their muscles much in climbing,—for instance, the lemur and sloth,—seems to be a provision for the maintenance of an uninterrupted circulation during muscular action.‡ It is probable that the influence of the blood is necessary both to the muscles and nerves; yet it is certain that even after complete arrest of the circulation in dead animals, and in amputated limbs, the nerves are still capable, when irritated, of exciting the muscles to action; and the muscles, also, of contracting, when the stimuli are applied immediately to them. The ligature of an artery does not altogether put a stop to the influence of the blood,—this fluid is still present in the small vessels; but the afflux of fresh arterial blood to the muscles and nerves is arrested. The experiments of Segalas also show, that when the capillary vessels are completely filled with blood, the circulation being nearly stopped by ligature of the lower part of the vena cava, the power of motion is still enfeebled. It is therefore certain that the arterial blood undergoes in the motor organs a change, which, while it gives the blood the venous character, renders it unfit to maintain in the muscles their contractile property,—in other words, that the property of con-

* Treviranus, *Biologie*, v. p. 281.

† *Journ. de Physiol.* 1824.

‡ The arterial plexuses, or *retia mirabilia*, are as frequent in parts not muscular as in muscular organs; we may instance the *rete mirabile* of the internal carotid artery in ruminants, and the largest of all known vascular plexuses, that connected with the portal vessels in the tunny (*thynnus*), which has been discovered by Eschricht and myself.

tractility requires for its perfect preservation the constant action of arterial blood on the muscular fibre. This is confirmed by the phenomena observed in the subjects of the cœrulean disease; in whom, on account either of a patent state of the foramen ovale, or ductus arteriosus, or a narrow condition of the pulmonary artery, the arterial and the venous blood are mixed, or the process of arterialisation imperfectly performed. Such persons are incapable of any great muscular exertion. In reptiles and amphibia the necessity of the influence of the blood upon the nerves and muscles, for the maintenance of the power of voluntary motion, is not so great. Frogs are still capable of voluntary movements when their heart is cut out; they can even move limbs which are connected with the trunk by the nerves alone; and even after I had expelled all the blood, by forcing a current of water into an artery till it escaped from the divided veins, I found that the muscles still contracted when irritated.

2. *Influence of the nerves upon the contractility of muscles.*—The question of the action of the nerves in exciting the muscles to contraction must not be confounded with that of their influence in the maintenance of the muscular contractility. Haller regarded the contractility of muscles as a vital property peculiar to them, and independent of the nerves; he named it “irritability.” This great physiologist, whose theory was adopted by Fontana, Soemmering, Nysten, Bichât, and others, taught that all stimuli acting on muscles excite their contractility without necessarily exerting their influence primarily on the nerves, and through them upon the muscles; and that the nervous stimulus is in fact merely one kind of the many stimuli by which the contractility of the muscular fibre may be excited. The proofs which Haller and his followers adduced in support of this theory have long lost their weight. The heart does not, as they supposed, act independently of all nervous influence, and its nerves are not insensible to external stimuli. The heart is, with reference to nervous influence, in the same condition as all other parts supplied by the sympathetic nerve. Not only can it be excited to contraction by galvanism, as has been observed by Von Humboldt, Pfaff, Fowler, Wedemeyer, and myself; but Humboldt and Burdach have succeeded in influencing its mode of action by irritating the cardiac nerves (see pages 191 & 663). The influence of the nerves on organic muscles can be demonstrated very distinctly also, as my experiments show, by irritating the cœliac ganglion, which causes the peristaltic motions of the intestines to become much accelerated (see p. 664). My own researches, and those of Wutzer, Retzius, and Mayer, have moreover sufficiently refuted Scarpa’s opinion that the sympathetic nerve has no connection with the anterior motor root of the spinal nerves and the motor cerebral nerves. These facts, however, merely lead us to conclude that the nerves of the heart

as well as the nerves of other muscles, transmit motor influence; they still leave undecided the question, whether in the sound body, and in a heart removed from the body, the cardiac nerves are necessary for the maintenance of the contractile power of the organ. The correctness of Haller's theory has been disputed by other physiologists,—as Whytt, Monro, Prochaska, Legallois, and Reil,—who contended that the motor power depends on a reciprocal action exerted between the nerves and muscles. Were such the case, the contractility of muscles would differ essentially from that of plants, which is excited directly by external stimuli, without the aid of nervous influence. In support of this opinion it is urged, that stimuli applied to the nerves excite the muscles to action; that narcotic substances, which seem to have a special action on the nervous system, when applied to the muscles, destroy their contractility; and that destruction of the brain and spinal cord also has the effect of diminishing the contractile power of the muscles. It must, however, be confessed that these arguments are by no means weighty. The duration of the muscular irritability is not less after the destruction of the brain and spinal cord, than after death from other causes; and poisoning with narcotic substances merely causes the influence of the brain and spinal cord to be no longer transmitted to the muscles. The irritability of the nerves and muscles is far from being destroyed in frogs by narcotic poisoning; I have seen the usual phenomena produced by the application of stimuli to the nerves or muscles for a very long time in frogs thus poisoned. Treviranus has adopted a middle course with regard to this question; and in accordance with what is observed in plants, which owe their irritability to the influence of light, but yet are excitable by other stimuli, believes that the influence of the nerves is a necessary condition for muscular irritability, but that all stimuli do not act by their intervention on the muscles. Tiedemann* agrees with Haller in regarding the muscular contractility as a peculiar property inherent in the muscles themselves, but believes the maintenance of this property in them to be dependent on nutrition and nervous influence; and further holds that the nerves do not merely conduct the stimulus which excites the muscular contraction, but afford an essential condition for the manifestation of the vital property of the muscles. This essential influence of the nerves may consist either in their imparting to the muscles their property of being affected by stimuli, in other words, of manifesting irritability; or it may be, that stimuli, even when applied to the muscles, must act first upon the nerves, and through their medium excite the contraction of the muscular fibre. It is evident, from the foregoing remarks of Tiedemann, that there are here involved two perfectly distinct questions: 1. Is the influence of the nerves necessary for the preservation of the vital pro-

* *Physiologie*, i. p. 547.—Translation by Gully and Lane, p. 295.

perty of the muscles by virtue of which they contract, and is this property lost when the nervous influence is cut off? 2. Are the nerves conductors, through the medium of which all stimuli act upon the muscles? does even the apparently direct irritation of the muscles themselves act first on the nervous fibrils distributed in the muscular substance, and only through the medium of them affect the contractile tissue? The first question may be decided in the affirmative, without the second proposition being necessarily admitted; but if the second receive an affirmative answer, the admission of the first is a necessary consequence.

1. Is the integrity of the nerves necessary for the preservation of the vital contractility in muscles? Nysten had observed, that, a short time after an apoplectic seizure, the muscles paralysed in consequence of the cerebral lesion still contracted under the influence of galvanism; and Wilson, on the authority of Sir B. Brodie, asserted that a nerve, whose communication with the brain and spinal cord was cut off, retained, for a considerable time, its faculty of exciting the muscles to contraction when irritated.* I had reasons for suspecting that the persistence of this excitability of a divided nerve, when its continuity had not been restored by regeneration, is not without its limits; and several experiments instituted with reference to this question by myself, in conjunction with Dr. Sticker, (see page 632,) have proved that, when the communication with the central organs of the nervous system is completely interrupted, not only the power of the nerves to excite muscular contractions, but with it the irritability of the muscles themselves, also, is gradually lost.

2. Are the nerves the sole conductors, through the medium of which all stimuli necessarily act on the muscles? The reasons for admitting such to be the case are the following:

a. The stimuli which excite the contractions of muscles, when applied directly to their tissue, are the same that produce the like effect when applied to the nerves. I have, it is true, frequently observed a difference in the action of stimuli on nerves and muscles; the mineral acids and alcohol namely, which, when applied immediately to the muscles, cause them to contract, had not the same effect when applied to the nerves. This difference does not, however, appear to be constant; for M. Humboldt has produced a tremor of the muscles by the application of alcohol, chloric acid, arsenic, and even of the metallic salts to the nerves; and Dr. Bischoff and Professor C. Windischmann have, I learn by private communication, in some instances seen muscular contractions produced in frogs by the application of mineral acids to the nerves.

b. The substances which destroy the contractility of muscles are also destructive of the excitability of nerves; for, although narcotic sub-

* Phil. Transact. 1833, pt. i. p. 62.

stances taken into the circulation, and destroying life by their action on the brain and spinal cord, do not immediately annul the excitability of the nerves and muscles of the body, — the muscles and nerves of frogs thus killed retaining their excitability for a long period, — yet the immediate application of these substances to the nerves and muscles destroys locally the muscular contractility and nervous excitability. Nerves immersed for a short time in a solution of opium lose their susceptibility of stimuli to the extent in which the fluid has acted on them; while between this part and the muscle they retain their property of exciting muscular contractions under the influence of stimuli. Muscle also immersed in solution of opium loses its vital properties to the extent to which the contact with the poison has reached. This similarity of action of narcotics on nerves and muscles renders it probable, that the effect of such substances in making muscles to which they are applied insensible to the influence of stimuli, is owing to their destroying the excitability of the nervous filaments distributed in the muscular substance.

c. M. Humboldt dissected away the finest branches of the nerves from muscles (those of the upper parts of the legs of frogs and the fins of fishes), and then found that they were no longer sensible of the stimulus of galvanism.

d. Very powerful electric discharges, acting either upon the muscles or upon the nerves alone, are stated to destroy very quickly the sensibility of the muscles towards external stimuli.*

e. The fact which I have observed relative to the different effects of the application of galvanism or mechanical irritation to the motor and to the sensitive nerves distributed in muscles, may also be adduced as an argument. Irritation of the gustatory branch of the fifth, namely, excited no contractions of the lingual muscles, nor irritation of the infra-orbital nerve any motion of the muscles of the nostrils and lips of animals. This fact proves that mere nervous influence, as a general property, does not act as a stimulus of muscular contractions in the manner of other stimuli; but that, for the excitement of muscles to contraction, a specific action of a special class of nerves is necessary.

f. Lastly, the extinction of the muscular irritability after a time, when the nerves have been paralysed by division, and their re-union prevented, is another, and perhaps the most conclusive argument in favour of the opinion that, for the excitement of muscular contractions, the integrity of the nerves ramifying in the muscles is necessary, and that the muscles themselves are not susceptible of the direct action of stimuli.

Although the conclusion just stated seems to be proved by the arguments which we have adduced, yet it is evident that the contractility

* Tiedemann's Physiologie, i. p. 551.—Translation, p. 297.

must be a property of the muscles themselves, and that the nerves cannot even during life impart to them a power which they do not themselves possess. But the manifestation of the contractile property of muscles presupposes a concurrent action of the nerves; the discharge of an imponderable agent by the nerves is indeed as necessary for causing certain portions or minute elementary parts of the muscular fibres to be attracted towards each other, as this attraction of the parts of the fibre towards each other is essential for the shortening of the whole fibre. The modes of contraction of the fibres under the influence of nervous energy have been considered and illustrated by facts in the preceding chapter. The strength of the attraction between the angles of the inflected fibres may be best estimated from the power which the living muscles possess of resisting in their contracted state the greatest extending force; while after death, when this power of reciprocal attraction in their particles is lost, they are very easily lacerated and torn asunder.*

Of the mode of action of the nerves on the muscles in exciting their contractions we are at present quite ignorant. MM. Prevost and Dumas† have described the nerves to be so distributed in the muscles that at each of the angles of the muscular fasciculi formed by their zigzag inflexion in the act of contraction, that is to say, at each of the points towards which other parts of the muscular fasciculus are attracted, or which attract each other, there is a nervous fibre running transversely across (see fig. 56, p. 887). These transverse nervous filaments, according to MM. Prevost and Dumas, form loops, returning to the nervous trunk after having passed across the muscular fasciculi at the points of their angular inflexion. Dr. Schwann has examined with the microscope the distribution of the nerves in one of the lateral abdominal muscles of a frog, which are so thin that even with a magnifying power of 450 diameters the light which is transmitted is sufficient to make the whole structure visible. A magnifying power of 100 diameters only, however, was found necessary. The following was the structure observed:—The nerve entering the muscle gave off numerous branches, which very soon divided into smaller branches, and so on, until from the smallest fasciculi the primitive fibres themselves issued. The smaller fasciculi, as well as the primitive fibres, were frequently seen to be given off at right angles. Very frequently the nervous fasciculi, and still more the primitive fibres, united in their course with other fasciculi, both with those running in the opposite direction, as well as with those following the same course. This anastomosis of the fasciculi rendered it impossible to discern whether any of the fibres, after forming a loop, did really return to the nervous trunk

* Compare the observations of Tiedemann, *Physiol.* p. 553.—Translation, p. 299.

† Magendie's *Journ. de Physiol.* t. iii.

whence they arose. The anastomosis of the fasciculi was so frequent that the muscle appeared interwoven, as it were, with an irregular nervous net-work. There was no determinate relation as to position, however, observed between the nervous fibres forming this net-work and the muscular fasciculi. Some few times Dr. Schwann perceived the following arrangement:—A fasciculus containing four nervous fibrils, for example, ran transversely across a muscular bundle; it gave off, at a right angle, first a primitive nervous fibre to the space between two primitive muscular fasciculi; then a second primitive fibre to the space between one of these muscular fasciculi and a third; a third nervous fibre came off from the nervous fasciculus, and entered the space between the third muscular fasciculus and a fourth; and the fourth nervous fibre was continued on to form an anastomosis with another nervous fasciculus. The three single primitive nervous fibres given off to the muscular fasciculi ran a certain distance parallel with them, and then disappeared without its being possible to ascertain what became of them. Perhaps they divided into much finer fibrillæ, like those which Dr. Schwann has discovered issuing from the ordinary nervous fibres, and forming a delicate anastomosis in the mesentery of the frog and the tail of the larva of the toad (see p. 604).

[MM. Prevost and Dumas observed only the smaller nervous fasciculi, not the primitive fibres. The later investigations of Emmert* and Valentin,† confirmed by E. Burdach,‡ have shown, however, that the nerves do really terminate in muscles by their primitive fibres forming loops or arches, the concavity of which is directed towards the nervous stem. According to Valentin and Burdach, the smaller ramifications of the nerve in the muscle, by a frequent interchange of filaments, constitute a plexus, from which the filaments forming the loops issue, and which they re-enter to return to the trunk of the nerve. Burdach states that this terminal plexus exists only near the extremity of the muscle, not equally throughout its whole extent.]

The observation of MM. Prevost and Dumas, that the nervous fibres form loops running transversely across the muscular fasciculi at the points of their angular inflexion, serves as the basis for their theory of muscular motion, according to which these transverse nervous loops are supposed to attract each other, and thus to shorten the muscular fibre. But in repeating their observations on living muscle it is evident that the parts of the nerves which in their transverse course are said to correspond to the angles of the zigzag inflexion of the muscular fasciculi, cannot be the primitive nervous fibres, but are entire fasciculi: for a portion of muscle in which it is possible to excite contraction must be

* Ueber die Endegungsweise der Nerven in den Muskeln. Bern, 1836.

† Nova Acta Nat. Cur. t. xviii. pt. i.

‡ Beitrag zur Mikroskopischen Anatomie der Nerven. Königsburg, 1837.

too thick to allow the primitive fibres of nerves to be seen; the primitive nervous fibres can be seen only by examining very thin laminæ of muscle with the compound microscope. The drawings which MM. Prevost and Dumas have given prove that they used only a simple lens. The observations, therefore, on which their theory is based, do not refer to the ultimate elements of the nerves and muscles. A part of their hypothesis consists in supposing that the nervous loops are traversed by electric currents; but, as we have seen at page 636, the existence of such currents of electricity in the nerves cannot be demonstrated. To obviate this main objection to their theory, MM. Prevost and Dumas suppose that the current of electricity in the nervous loops is double; and that for this reason, the two currents neutralising each other, the electricity cannot be detected by the galvanometer. They compare the fasciculi of muscular fibres to the magnetic needle of the galvanometer, which, like the muscular fibre, being subject to the action of opposite electric currents, is thrown into motion. Moreover, another inconsistency in the theory of MM. Prevost and Dumas is, that it attributes the shortening of the muscular fibre to the attraction of the nervous loops towards each other; and that the muscular fibre itself is consequently regarded as passive, and of no importance in the production of the phenomenon. This objection would, it is true, be avoided, were the hypothesis so far modified as to suppose the muscles to be charged with one kind of electricity, and a current of the other to be brought by the nervous fibres, the meeting of the positive and negative electricity causing the nervous loops and the muscular fibres to be attracted towards each other. In this case, however, the comparison of the muscular fibres with the needle of a galvanometer, which MM. Prevost and Dumas introduced into their theory, must be given up; and it is not easy to understand why the meeting of the two kinds of electricity should cause any attraction of the nervous and muscular fibre, why they should not neutralise each other as in other animal tissues without causing a reciprocal attraction of the component particles.

The same remarks apply to the theory of Meissner* (see p. 73), which supposes an electric atmosphere to be communicated by the nerves to the muscular fibres, and to cause these fibres to repel each other, like the electrified pith-balls on different threads fixed to an electric conductor; the two ends of the fibres being fixed must be approximated when the fibres are thus spread asunder at their middle by electric repulsion. Such a theory would afford an explanation of the appearance of alternate expansion and constriction of the primitive fasciculi of the muscles of insects. But, for electricity to have the effect here described, it is necessary that, like the pith-balls on the threads, the

* System d. Heilkunde aus allgemeinen Naturgesetzen. Wien, 1832.

fibres should be bad conductors of electricity; otherwise the equilibrium of the electricity would be restored without any motion being produced. The muscular fibres, however, are good conductors of electricity.

If, indeed, we reflect that the whole hypothesis of the similarity of the electric and the nervous principles is unsupported by any facts, and that, as we have shown at pages 634 and 635, these principles differ essentially as to their conductors and insulators, the theory of Prevost and Dumas, and any other modified theory of muscular motion as due to electric action, will be perceived to be baseless.

The muscular fibres certainly appear to become shortened during contraction in the intervals of the nervous loops which cross the fasciculi; it is probable, therefore, that the parts of the muscle which are traversed by the nervous loops, and which are principally exposed to the nervous influence, attract each other, and thus give rise to the zigzag inflexion of the muscular fasciculi. The regular succession of intumescences and constrictions of the primitive fasciculi of the muscles of insects also afford evidence of an attractive force exerted in the direction of the length of the fibre between smaller segments of it, than in the production of the zigzag inflexion. This attraction also will depend on aliquot parts of the fibre being thrown into a state of attractive energy by the nervous influence. In the present state of our knowledge, it is impossible to go further than this in explaining muscular contraction. The contractile tissue of some plants, — the *oscillatoria*, *mimosa*, &c. — and the contractile animal tissue which yields gelatin in boiling, seem to be enabled to curve, contract, or shorten themselves by virtue of a property, like the contractility of muscles, peculiar to these tissues in their vital condition. But the vital property of muscular fibres differs from the endowments of those other contractile tissues in requiring the influence or discharge of the nervous principle to set it in action.

Dr. Schwann is engaged in performing some experiments with the view of ascertaining whether the contractile force of a muscle diminishes or increases as the contraction of the muscle is greater. He employs, in these experiments, the *musculus gastrocnemius* of a frog with the following apparatus. The frog being fixed upon a board with the thigh in the horizontal position, its leg is raised so as to be perpendicular to the board, and the foot again flexed to the horizontal direction, in which position the limb is firmly fixed. The ischiadic nerve is then divided high up in the thigh, and dissected out as low as the knee, the greatest care being used not to injure any vessels: the nerve is drawn out towards the side, where it can be laid upon two wires which first run horizontally along the surface of the board, but soon turn down and perforate it, passing without coming in contact with each other to a galvanic

battery of a single pair of plates, with one pole of which one of the wires is connected, while with the other pole the second wire can be made to communicate by a slight pressure. The skin of the leg is left entire except at the heel, where a small incision is made for the passage of the tendo Achillis previously cut through in the foot. A thread tied to this tendon is connected with one arm of the beam of a balance suspended over the board. To the other arm of the balance a scale is attached. The arm of the balance which is connected with the tendon is lengthened to six times the length of the other arm by means of a straight wire attached to it; a slight contraction of the muscle producing, by means of this contrivance, a considerable motion of the balance-beam. The scale is now charged until it slightly overbalances the lengthened arm of the beam, which is prevented by a horizontal rod from rising, but can be carried downwards without meeting with any obstacle. The rod which stops the rise of the lengthened arm of the beam is so arranged that it can, with great accuracy, be altered by means of a screw to any higher or lower point, and is provided with a graduated measure to indicate the extent of its change of height. The apparatus being prepared with the long arm of the beam somewhat raised above the horizontal line, and the thread connecting it with the muscle being tense, the galvanic stimulus of a pair of plates of one square inch surface is applied to the ischiadic nerve. The contraction of the muscle causes the lengthened beam of the scale to be depressed. The level of the horizontal rod is now lowered to such an extent, that the contraction of the muscle can depress the arm of the balance but a very slight extent from the rod. The slight overbalance of the scale being regarded as 0, the extreme degree of contraction of the muscle is thus found. On the addition of weight to the scale, the beam could no longer be moved by the contraction of the muscle. At this point of its contraction, therefore, the power of the muscle was = 0. If, however, the level of the horizontal rod was gradually raised, there was found a point at which the contraction of the muscle moved the beam. At this less degree of contraction, therefore, the power of the muscle equalled the weight added to the scale. The amount of shortening, however, equalled one-sixth only of the extent to which the rod was raised. If double the former weight was laid in the scale, it was necessary to screw the rod up to a still higher level. Here then the power of the muscle was double that which it exerted at the former level, and the degree of shortening could be again found by referring to the instrument measuring the height of the rod. In this way the power exerted by a muscle under the influence of a determinate stimulus could be compared with the degree of its contraction. In performing the experiments, Dr. Schwann observed the precaution of applying the stimulus at equal intervals, and of ascertaining, after each circle of experiments,

whether the muscle would again contract to the same point as before, the weight in the scale being as 0, or even of repeating each experiment in the reversed order; for example, first noting the height of the instrument when the weight in the scale was 0; then when it was 50; and then 100 grains; and afterwards again 50, and at last 0 grain; taking the mean between the two numbers indicated at the same weight. The results of experiments instituted on a frog during the space of twelve hours in winter, a certain interval of time being allowed to elapse between the different experiments, were the following:

Experiments.	Weight in the scale of the balance, showing the force of the contraction.	Comparative elongation of the muscle, as measured by the elevation of the horizontal rod.	Rate of increase in length of the muscle, compared with the progressive increase of force.	
			Elongation of the muscle.	Weight indicating the increase of power.
Exp. 1.	0 grains . .	14.1		
	60 " . .	17.1	3.	from 0 to 60 grains
	120 " . .	19.7	2.6	" 60 to 120 "
	180 " . .	22.6	2.11	" 120 to 180 "
	0 at end of expt.	13.7		
Exp. 2.	0 grains . .	13.5		
	100 " . .	18.8	4.3	" 0 to 100 "
	200 " . .	23.4	4.6	" 100 to 200 "
	0 at end of expt.	14.4		
Exp. 3.	0 grains . .	13.7		
	50 " . .	18.7	4.3	" 0 to 50 "
	100 " . .	20.3	2.1	" 50 to 100 "
	50 " . .	17.7		
	0 " . .	14.1		
Exp. 4.	0 grains . .	13.5		
	100 " . .	19.1	5.6	" 0 to 100 "
	200 " . .	23.2	4.1	" 100 to 200 "
Exp. 5.	100 grains . .	16.8		
	0 " . .	12.7	4.1	" 0 to 100 "
	100 " . .	16.1	2.4	" 100 to 200 "
	200 " . .	18.7		
	100 " . .	16.1		
	0 " . .	11.7		

In the first two experiments, it appears, an uniform increase of force was attended with a nearly uniform increase of length of the muscle. In the last three, the rate of increase of force being uniform, the length of the muscle did not increase in the same proportion; but while the weight in the scales which balanced the power of the muscle was increased in a uniform ratio, the elongation of the muscle became less. The rest of the experiments instituted by M. Schwann afforded a precisely similar result. In those experiments, namely, which were performed earliest after the preparation of the frog, and in which, therefore,

the normal conditions of the system were least disturbed, the power of the muscles was found constantly to become greater in the same ratio as they were less contracted, or to diminish as the contraction of the muscle was greater. The later the experiments were performed, the more did the results differ from this law, which may therefore be regarded as pretty exact for the normal condition. The same law regulates the force of elastic bodies. In the case of the muscles, it affords a refutation of every theory which supposes the force of muscular contractility to be due to any one of the forces of attraction already known to us, all of which increase in energy as the attracted parts approach each other, in the ratio of the square of the distance; for, did such a force of attraction exist in the particles of the muscles in such intensity as to cause the approximation of these particles when distant from each other, its intensity should be still greater when the particles were already approximated, or, in other words, the muscle already somewhat shortened. The power of the muscle ought therefore to be least when it is in its ordinary elongated state, to increase as it contracts, and be greatest when the contraction has reached its extreme degree. The experiments of Dr. Schwann, however, prove that the very reverse of this is the case, that the power of the muscle is greatest when it is least contracted, and is 0 when the contraction has reached its greatest degree. The hypothesis of MM. Prevost and Dumas does not accord with this law demonstrated by Dr. Schwann, since the magnetic attraction increases in force the more nearly the attracted bodies approach each other. The theory of Meissner is less opposed to the facts. It supposes, not a direct attraction of particles, but a repulsion in the transverse direction of the muscle. The more the muscle is shortened by such repulsion, the more distant would the repelled particles be from each other, and the less effective would become the repelling force. Here, therefore, the contractile power would diminish as the contraction increased. Dr. Schwann has, however, ascertained, by mathematical calculation, that did the contraction take place, as Meissner supposes, the force would not decrease in equal proportion with the shortening of the muscle.

In concluding this discussion on muscular contractility, it appears necessary to direct attention to the fact that any sudden change in the condition of the nerves of muscles, by whatever cause it be produced, is productive of a shock to the muscles. The closing or interruption of the galvanic circle, sudden destruction of the nervous tissue, burning, chemical influence, mechanical stretching, and all such influences, appear to give an impulse to the imponderable principle of the nerves, by which either a current or oscillation of that principle towards the muscle is excited, whether the external influence heighten or depress the vital energy of the nerves themselves. Hence muscular contractions may attend any, even the most feeble state of the vital

forces, the nervous principle being capable of such motion or oscillation as excites the muscles to action, when any change is produced in the state of the nerves, even though the activity of the nervous principle is upon the point of being annihilated. We have here an opportunity of verifying the law laid down in the Prolegomena, that excitation is perfectly different from augmentation of the vital forces, — that an animal system may be stimulated to death, and that even the narcotic substances (the alterantia nervina), which have the property of producing so great a change in the nervous matter, give rise to symptoms of irritation or excitation, while they destroy the vital properties of the nerves.

SECTION II.

Of the different muscular movements.

CHAPTER I.

OF THE INVOLUNTARY AND THE VOLUNTARY MOVEMENTS.

THE most obvious distinction which presents itself in classifying the different muscular movements, is that between the voluntary and the involuntary. On closer examination, however, this division is found to be less natural than it at first appears. It does not agree with the differences in the forms of the muscular tissue; and there are many involuntary movements performed by muscles which are subject to the will,—movements in some cases following as regular a rhythm as do the motions of the heart. Certain muscles also, which are quite independent of the influence of the will, are nevertheless influenced by particular states of the mind; and lastly, the fact that the nerves have as great an influence over the involuntary as over the voluntary movements, deprives such a classification of much of its interest. The facts stated at page 850, were sufficient to show that a division of muscular movements into the voluntary and involuntary would not find any support in the anatomical structure of the muscular tissue; for, although the muscles of the organic parts of the system are distinguished by the absence of transverse striæ on the primitive fasciculi, and by the uniform non-beaded character of their fibres, while they act also independently of the will, yet the urinary bladder, which in respect of structure belongs to the organic muscles, is capable of some degree of voluntary motion. The fasciculi of the fibres of the iris again have not the cross striæ, and nevertheless a voluntary influence can be exerted indirectly upon the iris by turning the eye inward (see page 684). On the other hand, though the

muscles of the animal parts of the system are characterised by the transverse markings of the primitive fasciculi, and the beaded form of their fibres, at the same time that they are subject to the will, yet the heart here constitutes an exception, it being referrible by the structure of its fibres to the animal muscles, but with respect to its involuntary motion to the organic. There is no correspondence also between the colour of the muscles and their division into involuntary and voluntary. The voluntary muscles are generally red; but those of fishes are, for the most part, white. The muscles not subject to volition, as the muscular coat of the intestines, are generally of a pale colour; but the muscular gizzard of birds and the heart are composed of muscle of a deep red colour; while the muscular coat of the bladder, which is in some measure under the influence of the will, is as pale as that of the intestines. This difference of colour is certainly not merely owing to the greater or less abundance of blood-vessels, and of the red colouring matter of the blood. The peculiarity appears to reside in the muscular substance itself, which agrees with the cruorin of the blood in being rendered of a brighter red by the action of the atmosphere. The division of the muscular movements into the voluntary and involuntary finds, it is true, better support in the difference of the nerves supplying the different muscles; but even in this point of view it is subject to exceptions, the urinary bladder and iris, though supplied by the sympathetic, being capable of some voluntary motion.

If, indeed, we reflect that many muscles, which are ordinarily under the influence of the will, are nevertheless constantly being thrown into contractions in opposition to the will, as is the case, for example, with the sphincter ani; that some muscles belonging to the animal system are incapable of being made to act voluntarily, except in very few individuals, of which we have examples in the cremaster, &c.; and lastly, that all the voluntary muscles are also frequently excited to involuntary action, whether in consequence of "nervous reflection," or "associate nervous action," or by mere mental conceptions,—as in laughing, yawning, or sighing, and still more frequently by passions of the mind,—it will be seen that we have reasons sufficient for adopting a classification in which the internal causes of the different motions are more kept in view. Since the class of involuntary motions is founded on a negative character, some physiologists have more aptly divided the animal movements into the voluntary and automatic. The involuntary motions are, however, with reference to their causes, of such various kinds, that this division also appears to me to be objectionable; for what constitutes the difference between the automatic rhythmic movements of the heart and respiratory muscles, and the movements from reflex nervous action? The different causes of the muscular motions seem to be best kept in view in the following classes.

1. *Movements excited by heterogeneous stimuli, external or internal.*

By heterogeneous stimuli I understand here all other causes of muscular contractions than the mere impulse of the nervous principle itself. There are but very few instances in which such stimuli give rise to muscular actions in the normal state of the body; such is the case, however, for example, with the stimulus of the bile and fæces, which excite the movements of the intestines; with the stimulus of the urine causing the bladder to contract, &c. For the production of muscular motion, a change in the state of the nerve supplying the muscle is necessary. It is indifferent whether this change in the nerve be effected through the medium of its anatomical connections with the central organs, or from its own blood-vessels, or whether the influence which produces it be derived entirely from without. All muscles, animal as well as organic, are equally capable of being excited to motion in this manner; but the movements thus produced are always involuntary, whether the muscle be ordinarily withdrawn from the influence of the will or not. The point at which the stimulus may act is threefold.

a. It may act on the muscle itself.—In this case, the nervous fibrils distributed in the muscle are primarily affected, and through their influence the muscular fibre is made to contract (see page 898). The direct application of an external stimulus causes the heart, the intestinal canal, the urinary bladder, and all the involuntary as well as the voluntary muscles, to contract. There is, however, this difference to be observed, that the movements thus excited in the organic muscles, which are under the influence of the sympathetic nerve, are not always a rapid momentary contraction immediately following the application of the stimulus, as is the case in the animal muscles, but either a gradual increasing contraction, ensuing more slowly, enduring longer, and reaching its maximum when the action of the stimulus has ceased,—which mode of contraction is seen in the intestinal canal and uterus,—or a long-continued modification of the ordinary rhythmic action of the organ,—as when the heart is irritated. (See page 731.)

b. On the nerve.—The application of a stimulus to the nerve before it has reached the muscle has the same effect as irritating it in the muscle itself. This is a fact well known with regard to the cerebro-spinal nerves; but that it is true of the organic or sympathetic nerves also has been more recently discovered. (See vol. i. pp. 732 and 733.)

c. On the central organs of the nervous system.—Irritation of the brain and spinal cord always gives rise to contractions in the muscles which derive their nerves from the irritated part of the nervous centres. The influence of the brain and spinal marrow on the movements of parts supplied with cerebro-spinal nerves has been considered at page 840; and the influence of the same parts on organs the nerves of which be-

long to the sympathetic system, at page 730. The experiments of Dr. Wilson Philip tend to show that every part of the brain and spinal cord can exert an influence on the motions of the heart; while, in the case of the muscles supplied by cerebro-spinal nerves, particular parts of the brain and spinal cord are always connected with particular muscles.

An important difference is found to exist in the action of irritating agents. Many stimuli,—as mechanical irritants, heat, electricity, the alkalies, and other substances,—excite muscular contractions when applied directly either to the muscles themselves, to the nerves, or to the central organs of the nervous system. Other substances, on the contrary, excite no contraction of the muscles, unless when they act on the central organs of the nervous system through the medium of the circulation: thus the local application of narcotics to a muscle or nerve destroys their irritability or excitability at the part acted on, but gives rise to no muscular contractions; while the same substances produce the most violent convulsions, when, mixed with the blood, they exert their influence on the brain and spinal cord. That in animals poisoned by narcotics the convulsions are due to the irritation of the great nervous centres, is evident from the fact that division of a nerve puts a stop to the tetanic convulsions in the part which it supplies. (See page 629.)

2. *Automatic movements.*

By automatic movements it is intended here to designate all those muscular actions which are not dependent on the mind, and which are either persistent or take place periodically with a regular rhythm, and are dependent on normal natural causes seated in the nerves or the central organs of the nervous system. The cause of the rhythmic movements may be either in the sympathetic nerve or the great nervous centres, but never in mere cerebro-spinal nerves.

a. Of the automatic movements dependent on the sympathetic.

These movements are presented, 1, by muscles of which the primitive fasciculi are marked by transverse striæ,—namely, by the heart; and 2, by muscles of which the fasciculi have no transverse markings,—as the intestinal canal, uterus, and urinary bladder.

The automatic movements of the heart, like those of the animal muscles of the body, are contractions of momentary duration succeeding each other quickly. The automatic motions of the muscles of the second series are more gradual and more enduring, and their intervals of rest are much longer. Whether this difference be owing to the different structure of the muscle, or to the nature of the nervous influence, is not known. The fact that the bladder, although it may be made to contract voluntarily, yet is not capable of a rapid contraction, is in favour of the

kind of motion being due to a peculiarity of the muscular tissue. The action of the urinary bladder being, when the viscus is distended, periodically increased in force, is so far referrible to the automatic movements, but otherwise does not belong to them.

In all the automatic movements of the viscera of organic life, without exception, there is observed a certain order of succession in the contractions; one part of the viscus contracts before another, and the motion thus traverses the organ in a determinate direction during each period of the rhythm. In the heart of the frog, the motion is seen to commence in the *venæ cavæ*, and to proceed through the auricles and ventricle till it reaches the *bulbus aortæ*, which contracts last. In the intestine, the movement travels in a vermicular manner from above downwards; and a second movement, beginning at the upper part of the intestine before the first has completed its course, affects the parts in the same order. The rhythmic motion is seen even in the lower part of the *œsophagus*. It is proportionally very feeble in the morning. The contractions even of the uterus of animals is vermicular; at least they are so, as I have witnessed, in the rat when excited by irritants locally applied. The periodic contractions of the uterus are generally observed to occur only during parturition; they in rare instances take place during pregnancy, but are then more feeble. The action of stimuli on organs endowed with automatic motion does not generally alter the order of the contractions; to produce such an effect, the irritation must increase to a great degree, and an antiperistaltic motion is then produced; but this reversed order of the automatic movements may also attend the interruption of nervous influence in cerebral affections. Irritation of organs presenting the automatic movements has also an influence on the rapidity and force of the contractions; stimuli, whether external or internal, acting on the heart, cause it to beat quicker and more forcibly. In acute diseases of great intensity, which make such an impression on the central organs of the nervous system as to give rise to fever, the heart not only acts more frequently than natural, but even the mode of contraction of its fibres is altered, causing hardness of the pulse; hence in fever, while the powers of the system are unimpaired, the pulse is hard, strong, and quick. In proportion as the powers of the system decline, the impression of the disease on the central organs continuing, the beat of the heart, though it retains its altered character, becomes feeble; and the pulse accordingly, still hard, also becomes weak, while it increases in frequency. A hard, full, and frequent pulse, therefore, is in acute disease an indication that a violent impression is made on the nervous centres, the vital powers not being essentially impaired; while, in proportion as the pulse, still hard, becomes more feeble and frequent, we know that the vital powers are sinking. The pulse becomes slower in many affections which are not inflammatory, but are attended with

interruption of the functions of the central organs of the nervous system, —such as syncope and apoplexy. The motions of the intestinal canal are rendered both more energetic and quicker by external irritation, as when the intestine is exposed to the air; or by internal irritation of its mucous membrane, as in diarrhœa: irritation of the spinal cord also is productive of spasmodic automatic movements of the intestinal canal and uterus. The same increase of the automatic movements is produced by irritation of the sympathetic nerve; such, at least, is the effect of irritation of the cœliac ganglion, by the application of caustic potash, on the intestines of the rabbit.

Many of the organs which present the automatic movements are provided with sphincters. While the automatic contractions of these muscular tubes or sacs become periodically stronger, the sphincters, as for example the sphincter vesicæ or os uteri, remain for a time constantly closed; but their resistance is at last overcome, and they are dilated by the contents of the viscera, which are thus driven against them with increasing force. The antagonism which subsists between the sphincters and the muscular coats of the viscera is evidently not so much due to any cause seated in the muscles themselves, as to the mode of action of the nerves in them. Reil* supposed that there was a polarity of action between the fundus and the cervix uteri; but this supposition does not make the matter clearer. The dilatation of the sphincters appears to be for the most part the consequence of the pressure exerted against them from within. After the expulsion of their contents both the muscular viscera and the sphincters gradually contract again, — the sphincters, as before, uninterruptedly, and equably, and the coat of the hollow viscus with periodic increase of intensity. The *after-pains* of the parturient woman seem to be the expression of the rhythmic contractions of the uterus.

The primary cause of the rhythmic contractions of the organic muscles is connected with the mode of action of the sympathetic nerve on the muscles: it is not seated in the brain or spinal cord. This constitutes an essential distinction between the automatic movements of the organic and those of the animal muscles. The rhythmic contractions of the heart continue even when it is removed from its connections in the body. This continued action of the organ is not due to the stimulus of blood, for it is kept up with the same regularity when the heart is emptied of all its blood. The action of the heart continues also in vacuo; it cannot, therefore, be owing to the stimulus of the air. The intestinal canal likewise still presents its peristaltic motions when removed from the body; and the separated oviduct of a turtle has been seen to contract so as to expel the ova.

The inquiry as to the cause of muscular contractility (see p. 896)

* Reil's Archiv. Bd. 7.

leads to the conclusion that a concurrent action of the nerves is always necessary for the act of muscular contraction; and hence, as well as from the fact that stimuli applied to the cœliac ganglion produce a change of some duration in the peristaltic movements of the intestine, we must infer that the organic nerves distributed in the muscular substance have a principal share in the production of these automatic movements, and that the rhythmic contractions of these organic muscles are not independent of the nerves, as Haller believed. The cause of the rhythm may be in the muscular fibres themselves, or it may be in the nerves. If it be in the muscular fibres, we must suppose that while the action of the nerves is constant, the muscular fibres of the heart lose for a time their capability of contracting, which is restored during a short repose. If the cause of the rhythm have its seat in the nervous fibres, the susceptibility of the muscle must be persistent; but the current of nervous principle must, from some causes appertaining to the nerves, be emitted from them, so as to act on the muscles, only periodically. The hypothesis that the heart each moment, or eighty times in a minute, loses its susceptibility of the still constant influence of the nervous principle, and as often regains it, is improbable, from the circumstance that all other muscles are capable of persistent action if the stimulus be continued. So rapid a restoration of the excitability also is as improbable as the frequent loss of it, for the renovation of the excitability in exhausted muscles requires not repose alone, but also the action of the arterial blood circulating in them; and arterial blood can no longer circulate in the vessels of a heart cut from the body, and nevertheless its rhythmic movements continue under such circumstances, even when the blood is removed from its cavities. The second hypothesis, namely, that the excitability of the heart is persistent, but the action of the nerves on it periodic, is more probably correct.

This second hypothesis requires a more close consideration. The effect which irritation of the cœliac ganglion produces on the motions of the intestines renders it probable that this ganglion has a share in the production of the rhythmic motion; but even after the caustic potash used to irritate the ganglion has destroyed its structure, the rhythmic motions still continue for a long period, and even the intestine alone, separated from the mesentery, continues its peristaltic contractions. The power of determining the muscular fibres to peristaltic motion must therefore be possessed by the sympathetic nerves of the intestines after they have issued from the ganglion,—indeed, by their branches contained in the coats of the intestines. Confirmatory of the conclusion that the branches of the sympathetic nerves distributed to the organic muscles have the same influence on the peristaltic motions as the cœliac ganglion is proved to have, is the fact that a minute examination of the branches of the sympathetic often detects the presence of very small secondary

ganglia distributed irregularly in them. Retzius* has observed such minute ganglia on the twigs from the sympathetic, which accompany the divisions of the fifth nerve. I have once seen such small ganglionic enlargements on the communicating branch between the sympathetic and a dorsal nerve, and in the neighbourhood of the posterior extremity of the prostate, in those branches of the hypogastric plexus which I have discovered to enter the posterior part of the corpora cavernosa penis, both in the human subject and in the horse. If portions of the sympathetic nerve of considerable length be minutely examined, small knot-like enlargements, which might easily be overlooked, are not unfrequently seen, when the fasciculi are separated from each other to some extent. Remak has frequently isolated such minute knots, which are easily discoverable by the naked eye. On the minute microscopic filaments of the sympathetic nerve discovered by Dr. Schwann in the mesentery of the brown or fire-toad (*rana bombina*), he has seen small enlargements separated by considerable intervals. These small enlargements of the sympathetic are not identical with the varicosities observed by Ehrenberg on the primitive fibres of that nerve.

It has been proved that the automatic motions of the organic muscles, like all muscular motion, depend primarily on the influence of the nervous principle; that the cause of the rhythm of these automatic motions is connected, not with the nature of the muscular fibres, but with the peculiarity of the nervous system of the organic muscles; and that the celiac ganglion has the property of exciting, when irritated, the peristaltic motions of the intestines. It appears, moreover, that the sympathetic nerve retains its ganglionic structure even in its more minute ramifications; and the power of the intestine to perform its peristaltic motions is found to be preserved even when it is separated from the mesentery. From these facts, then, I conclude that even the minute branches of the sympathetic which ramify in the intestinal coats have the same power of causing periodic contractions as the celiac ganglion was proved to possess. The explanation that applies to the peristaltic movements of the intestines has the same force with relation to the rhythmic motion of the heart; the first observed motion of the heart in its simple tubular condition is indeed of a peristaltic nature. Since, therefore, not merely the larger ganglions of the sympathetic, but even its ultimate ramifications in the tissues of organs, seem to possess the power of giving rise to periodic motions, we can understand how the rhythmic movements of the heart, intestine, and oviduct of the turtle are enabled to continue when these organs are removed from their connections in the body.

Hypothetical explanation of periodic movements.—Let us now inquire

* Isis, 1827.

whether it be not possible to frame an hypothesis which shall afford some explanation of the periodic action of the nervous principle in parts under the influence of the sympathetic. When a definitive explanation of phenomena is yet impossible, an hypothesis which is not opposed to the facts, but on the contrary accords with them, and which opens a new field for further research, is admissible even in an exact science founded on facts. Such an hypothesis appears to be the following:—It being supposed that the sympathetic nerve is the seat of constant currents of the imponderable nervous principle transmitted from the centre, or point of origin, to the periphery in the organs supplied by the nerve, the question is, How can the constant motion of the nervous fluid be changed to a periodic motion? This may be illustrated by comparing it with what takes place when a constant current of electricity meets with an imperfect conductor. Thus, when a conductor of electricity is held at some distance from the electric machine, which is kept in a state of constant electric excitement, the electricity is given off periodically in sparks. The dry air, which intervenes between the conductor of the machine and the conducting substance held near it, is an imperfect conductor of electricity, and impedes the progress of the electricity from the machine to the conducting body, until it accumulates in such quantity as to overcome the impediment thus offered to its course; and hence the electricity escapes in a succession of sparks. We intend this merely as an illustration of the mode in which the current of the nervous principle may be rendered periodic: we have refuted the idea of the identity of the nervous and electric principles in another part of the work. The ganglia of the sympathetic nerve have frequently been compared to imperfect conductors; and we have seen that the nervous principle certainly travels much less rapidly in the sympathetic than in the cerebro-spinal nerves (see Book III. section III. chap. v. parag. vi.): some impediment, therefore, to the motion of the nervous principle must exist in the sympathetic which is not present in other nerves, where the influence of a stimulus applied to the nerve is communicated with immeasurable rapidity to the muscle so as to cause its instantaneous contraction. The sympathetic nerves may therefore be compared to imperfect conductors, whether the insulating influence be seated in the ganglia or in the nervous fibres themselves. This being granted, the cause of the periodic action, or periodically increased action of the nervous principle on the muscular fibre, is obvious. The ganglionic parts of the sympathetic nerve will, as imperfect conductors, tend to arrest the current of the nervous fluid. The general current, on the other hand, following the peripheral distribution of the nerve, strives to reach the organic muscles. As soon as the insulating particles of the sympathetic have in this way received the maximum of the nervous principle of which they can resist the progress, they suddenly com-

municate it to the organic muscles; the current of nervous influence then begins again to be arrested for a time. Did such a process take place in the sympathetic nerve, even to its peripheral ramification in the muscles, the ganglia, which are met with in such frequency on a small scale in it, must play an important part as imperfect conductors or partial insulators of the nervous principle.

The muscular movements dependent on the sympathetic nerve have not universally an intermittent type; the sphincters, which are subject to the influence of the sympathetic, have, for example, a persistent type of action. In these last muscles, then, the current of the nervous principle is uninterrupted. The sphincter of the urinary bladder is almost constantly in action; it is subject to only occasional relaxation. It is remarkable that the bladder, which presents this constant muscular action, receives, not merely organic nerves, but also cerebro-spinal nerves, in which the current of nervous influence can go on uninterruptedly. The nerves of the urinary bladder are derived not merely from the hypogastric plexus, but in part from the third and fourth sacral nerves. The persistent contraction of the sphincter of the bladder is, in fact, not so much dependent on the sympathetic nerve as on the cerebro-spinal nervous system. The sphincter is paralysed by diseases seated in the brain or spinal cord. Division of the spinal cord paralyses the sphincter vesicæ as well as the sphincter ani, which is under the influence of the will; while the motions dependent solely on the sympathetic nerve go on independently of the brain and spinal cord even when these organs are removed from the body.

Admitting that the organic nerves have really the property of arresting the transmission of the nervous principle for a time, so as to prevent its rapid escape, the continuance of the motions in viscera supplied with nervous influence by these nerves for a considerable time after their connection with the brain and spinal cord is at an end, will be intelligible. The organs under the influence of the sympathetic are not, however, wholly and permanently independent of the brain and spinal cord. When these central organs of the nervous system are exhausted by want of rest and sleep, or by the impression of acute diseases, the dependence of the organic viscera on them, which is not observable when the supply of nervous influence to the sympathetic is arrested only for a short period, becomes as evident as in parts supplied by cerebro-spinal nerves; for the power of the heart and other organic muscles then becomes exhausted.

b. Of the automatic movements dependent on the central organs of the nervous system.

The same muscles being engaged both in the involuntary movements of respiration and in voluntary movements, it would naturally occur to the

mind that these different modes of action of the same muscles were determined by different nerves. Sir C. Bell* endeavoured to prove by experiment that the power of performing one of these kinds of movements may be lost, the muscles still preserving their capability for movements of the other kind. He told a patient with hemiplegia to raise his shoulders; in spite of the greatest effort, the shoulder of the sound side only was raised. The voluntary motions of the thorax appeared to be lost on the paralysed side; but, when the patient was directed to take a deep inspiration, the shoulder of the paralysed side was raised as well as that of the sound side. This, however, merely proves that a patient who has the power of taking a deep inspiration, still possesses voluntary influence over the muscles which raise the shoulder. Sir Charles Bell, however, explained the result of this experiment by supposing that the *nervus accessorius*, which is distributed to the trapezius and levator scapulæ muscles, may retain its power as a respiratory nerve, while the branches of the spinal nerves sent to the same muscles are paralysed; and thus that the power of elevating the shoulder during respiration, to free the thorax from the weight of the shoulders, which is due to the influence of the spinal accessory nerve, may be retained while the same movement as a mere voluntary effort cannot be performed, and *vice versa*. The same physiologist divided the *nervus accessorius* in an ass, and states that the action of the trapezius and levator scapulæ in respiration was lost, but that the animal still possessed voluntary power over those muscles. This statement with regard to the *nervus accessorius* may be granted to be true, though it is not yet sufficiently confirmed: the *nervus accessorius* has certainly, however, equal power with the spinal nerves in exciting the trapezius muscle to simple voluntary motion. Many respiratory muscles—as the diaphragm, for example,—have but one kind of nerves, and it is not in the most remote degree probable that these nerves contain special fibres for the respiratory movements, and others for the excitement of voluntary motion. The same nervous fibres are engaged in regulating the rhythmic movements of involuntary respiration, and in determining the muscular actions by which we voluntarily alter the mode of respiration.

The type and rhythm of these movements have their source, not in the nerves, but in the brain and spinal cord themselves. The cerebral and spinal nerves are merely conductors of the influences emitted by the central organs; if the conducting nerves be divided, the automatic movement ceases. This is the case with the motions of the diaphragm and all the other respiratory muscles, and also with those of the sphincter ani and other sphincters of the animal system.

The automatic movements dependent on the influence of the central organs have, like those regulated by the sympathetic nerve, in part an intermittent, and in part a persistent type. The respiratory movements

* Natural System of the Nerves, 8vo. 1824, p. 212 to 215.

are automatic and intermittent; the action of the animal sphincters is automatic, but persistent. All the movements of the group we are now considering are executed by muscles which are also subject to the will.

Automatic movements of muscles of the animal system with an intermitting type. The respiratory movements.—The respiratory movements comprehend motions of the diaphragm, of the abdominal and thoracic muscles, and of the laryngeal muscles by which the glottis is dilated and closed. Under some circumstances, respiratory movements affect the muscles of the face, and, in many persons during sleep, those of the soft palate. The nerves engaged in the production of these movements are the phrenic, the spinal accessory, the vagus, (for the muscles of the larynx,) a great part of the spinal nerves, and, for the respiratory movements of the face, the portio dura of the seventh. The source of the nervous influence for all the respiratory motions is the medulla oblongata (see page 348). But how is their rhythmic character to be explained? Does it consist in a periodic action of the inspiratory muscles only, or in two alternate actions of the inspiratory and expiratory muscles? The problem would be more simple, were the former the case. In fact, during ordinary perfectly tranquil respiration, the muscular movements do consist only of periodic inspiratory efforts of the diaphragm, the thoracic and laryngeal muscles; expiration is effected by the return of the parts by virtue of their elasticity to their former state. The pressure of the abdominal muscles has a share in the production of expiration, but probably only so far as their constant pressure on the abdominal viscera tends to force up the diaphragm and diminish the cavity of the thorax. Sometimes when from internal causes the inspiration takes place abruptly and suddenly, the expiration remains unaffected, and follows gradually as usual. In very frequent and laboured respiration, however, during a state of excitement, the movement of expiration becomes active, and the rhythm of the respiratory movements consists of two distinct acts: in the frog it consists of three acts (see page 345). To express these facts in physiological terms: the medulla oblongata, in giving rise to the movements of respiration, is the seat of a periodic discharge of the nervous principle towards all the muscles of inspiration, and alternating with this,—in many cases, at least,—of a movement of the nervous principle, whether a current or an oscillation, towards the expiratory muscles. In seeking the causes of this action of the medulla oblongata, two questions present themselves:

1. What is it that excites the medulla oblongata to determine the respiratory nerves to action in the human subject after birth, while in the fœtus it does not exert this influence? The exciting cause must either be sensations arising in the respiratory organs, and making an impression through the medium of the vagus (which is the sensitive nerve of the lungs) on the medulla oblongata, or it must be the impres-

sion made by the arterial blood on this highly excitable part of the nervous system. Neither the sensitive impressions produced by the atmospheric air in the lungs, nor a sense of the want of air, can be the cause of exciting the medulla oblongata to action; for I have divided both vagi nerves and both superior laryngeal nerves, and have even entirely separated the larynx, and still the respiratory movements continued in regular order up to the time of death. The theory of M. Kind, that it is the stimulus of the air acting on the cutaneous nerves, and transmitted to the spinal cord, which gives rise to respiration as a reflected movement, is not very probable; for a frog wholly deprived of its skin continues to respire as before; and a frog with its head only in the air will breathe equally well, whether the skin of its body be immersed in water or surrounded with air. If the stimulus of water acting on the skin were sufficient to excite the respiratory movements, the foetus of mammalia ought to perform them in the uterus. It is evident, therefore, that the cause of the first respiration of the infant, as well as of the continued respiratory movements, must be some influence which could not act in the foetal state, but which comes into operation immediately after birth; and this influence is not the stimulus of atmospheric air either in the lungs or on the skin. The cause of the first respiration can only be the impression made on the medulla oblongata by the arterial blood, which is formed in consequence of the first entrance of the air into the respiratory organs, and in less than a minute reaches the primum movens of the respiratory movements in the central organs of the nervous system. The arterial blood is also very beautifully shown to be the cause of the continuance of the respiratory movements throughout life by my experiments on frogs, in which I made the animals breathe for several hours in hydrogen; after a time respiration ceased, although life was not extinct. For a time the respiratory movements were renewed when the vessel in which the animals were included was agitated; but, after a longer period had elapsed, this was no longer the case. If, after being thus confined in hydrogen for two or three hours, the frogs are taken out and exposed to the atmosphere, they appear perfectly dead; not the least sign of motion or sensation is observable in them. The heart being laid bare, if it is found to have ceased to beat, the animal will not revive. If it still beats, though at intervals of half a minute or a minute, the frog will generally recover without any external stimuli being applied, merely from the gradual oxidation of the blood in the vessels of the lungs, the want of which arterialisation was the cause of the asphyxia. The blood impregnated with oxygen, however slow the action of the heart, must at length reach the brain and the medulla oblongata, which then begins again to emit nervous influence. The first signs of the revival of the frog, which lies quite motionless, is the retraction of the extremities when the skin

is pinched; after a short time it is seen to respire at long intervals, and in a few hours is quite lively. The cause, therefore, of the first excitement, and of the continued action of the medulla oblongata in determining the respiratory muscles to action, is the arterial blood.*

2. What regulates the rhythm of the respiratory movements? The action of the arterial blood on the medulla oblongata is constant; and though the motion of the blood in the small arteries be accelerated from time to time synchronously with the heart's action, yet this pulsatory motion does not bear any relation to the rhythm of the respiratory movements: how then does the continual excitement of the medulla oblongata give rise to a periodic action of this centre of nervous influence on the respiratory nerves? The rhythm here might be supposed to be owing to a similar cause with the rhythmic automatic motions of organic muscles, namely to the nervous influence destined for the respiratory nerves being arrested in the medulla oblongata by some insulating power, which is only overcome when the nervous influence constantly excited has accumulated to a certain amount: or it might be thought connected with the fact that the power of nerves to

* [The arguments adduced by Professor Müller appear to the translator to be by no means sufficient to refute the opinion, that the respiratory movements are the result of reflex nervous action excited at first by the contact of the air with the surface of the new-born infant, and afterwards by sensitive impressions in the lungs. The continuance of the respiratory movements in animals after the division of the *nervi vagi* may be due, as Dr. Hall supposes, to the transmission of voluntary influence from the brain to the respiratory muscles; since respiration will not go on, he states, when both nerves are divided and the cerebrum removed, though either of these operations may be performed singly without checking the movements; or, what is perhaps more probable, the sensitive impressions in the lungs, which are usually conveyed to the medulla oblongata by the *nervi vagi* and sympathetic simultaneously, may now be transmitted solely by the pulmonary branches of the latter nerve, which is the explanation proposed by Mr. Grainger (on the Spinal Cord, p. 89), and Dr. J. Reid (Edin. Med. and Surg. Journ. No. xlix.) The last named physiologists have shown by experiments that after the *nervi vagi* have been divided, animals still feel the sense of suffocation, the "*besoin de respirer*," when the supply of air to their lungs is interrupted. Again, the fact that a frog denuded of its skin or immersed in water will continue to breathe, and the circumstance of the liquor amnios,—a fluid of the same or nearly the same temperature as the body of the fœtus,—not exciting in it respiratory movements, do not prove that the impression made on the cutaneous nerves by the cooler air when the fœtus escapes from the uterus, may not be the exciting cause of the first inspiration. Such was the explanation of the first inspiration proposed by Sir G. Blane, and it is in some measure confirmed not only by the well-known fact that cold water or cold air suddenly coming in contact with the surface of the body gives rise to a deep inspiration, but also by an interesting observation made by Dr. Heming, of a child just born apparently asphyxiated beginning to breathe when the cool air was admitted by raising the bedclothes. (Dr. Hall's *Memoirs on the Nervous System*, p. 88. A similar but more extraordinary case is related by Dr. Wagner. *Medicin. Zeitung*, Jan. 1838. *Brit. and For. Med. Rev.* April, 1838.) The theory of Professor Müller, that the cause of the first respiration is the impression made on the medulla oblongata by the arterial

transmit nervous currents or vibrations, or the power of muscles to contract under the influence of the nervous impulse, has a certain limit, ceasing after a certain time until restored by the vital process going on in the capillary blood-vessels.

In the muscles of the extremities the power of continued action is evidently much greater than in the muscles engaged in respiration; thus we can continue standing or bear a weight for a long period, but can prolong the movement of inspiration or that of expiration only for a very limited time. Any muscular motion, however, may be persisted in for a very long period, if made to alternate with other motions. It is not, therefore, the nervous principle that is deficient in these cases, for there is nervous influence sufficient for other muscular actions: the defect must be either in the conducting power of the nerves, or in the contractility of the muscles; one or the other of which, or perhaps both, are exhausted by the movement performed. The regular alternation of inspiration and expiration, and the regular succession of the three acts in the respiration of frogs, show pretty distinctly that neither

blood, is clearly open to the objection that the blood could not be rendered arterial, and therefore could not excite the medulla oblongata, until respiration had been at least once performed. The phenomena presented by the frogs asphyxiated by immersion in hydrogen gas, the last argument brought forward by Professor Müller, are perfectly in accordance with the theory which attributes the continuance of respiration to the transmission of sensitive impressions from the lungs to the medulla oblongata, and a consequent reflected action; for while venous blood was circulating in the vessels of the brain and spinal cord, they were incapable of reflex action, no motion could be excited in the apparently dead animal; but, when the circulating blood became arterialised, pinching the skin, we are told, excited a retraction of the limbs, which, whether a reflected or voluntary motion, showed that the nervous centres had regained their sensibility of impressions, and it is very possible that the restorative action of the arterial blood on the medulla oblongata consisted merely in its rendering it susceptible of the sensitive impressions transmitted from the lungs. It appears also to the translator to be more probable that the blood was arterialised in this experiment chiefly through the medium of the skin; for we know that frogs will live many hours after their lungs are extirpated; while, immersed in oil, they die in less than an hour (see page 294); and in an asphyxiated frog the entrance of air to the lungs, and its renewal, must be very limited. The cause of the respiratory movements was supposed by Dr. Whytt (Works, p. 94,) to be an uneasy sensation in the lungs produced by the accumulation of blood in them at the end of each expiration, and exciting the act of inspiration through the intervention of the brain and spinal cord. Expiration he believed to be the result of the reaction of the parietes of the thorax previously stretched. The exciting cause of the reflex nervous action for each inspiration is now supposed to be either the influx of venous blood into the lungs, or the presence of carbonic acid in the air-cells. Dr. Whytt referred the commencement of respiration in animals to the same cause as its continuance,—namely, an uneasy sensation in the lungs arising from a great quantity of blood which before passed through the aorta being now, on account of the interruption of the placental circulation, thrown into the vessels of the lungs through the pulmonary artery. Other physiologists regard the cessation of the supply of partially arterialised blood, which the lungs previously received from the placenta, as the exciting cause of the first inspiration; it has probably some influence.]

of the preceding modes of explanation is sufficient to account for them ; but that some unknown influence is in operation in the medulla oblongata, which causes each movement of the nervous principle towards the inspiratory muscles to be followed by a motion of the same principle towards the muscles of expiration, and *vice versâ* ; so that, as in a pendulum or balance, the movement in one direction necessitates the movement in the opposite direction. In fact, at the end of a voluntarily prolonged inspiration, we feel not merely exhaustion of the inspiratory muscles, but the striving of an irresistible force opposed to the movement of inspiration ; and so likewise, after a long-continued expiration, the necessity of inspiring is felt ; and, though this may be delayed for a time by an increased voluntary effort, the inspiratory movement at length necessarily ensues. Were the cause of the alternation of the respiratory movements not seated in the medulla oblongata itself,—were it merely the temporary exhaustion of the nerves and muscles,—the inspiratory and the expiratory muscles might voluntarily be made to act simultaneously, and both to desist from action simultaneously, and again act at the same time. Moreover, the regular alternation of inspiration and expiration cannot be occasioned by the communication to the central organs of the nervous system of a feeling of the necessity of expelling the air impregnated with carbonic acid, and of taking in pure air ; for after the division of both vagi nerves in the neck, and of both superior laryngeal nerves, all sensations in the lungs must be lost, still more completely even than in sleep, and nevertheless the regular respiratory movements continue in animals after this operation [see note to page 920]. It has been supposed (see page 355) that the different states of fulness of the great venous trunks and of the veins of the brain, consequent on the diminished and increased capacity of the thorax in respiration, may be the cause of the rhythm of the respiratory movements. But this is evidently arguing in a circle. Besides, the periodic motion of the branchial opercula in fishes, where no pressure is by this means exerted on the veins, proves the impulse to respiration to be completely independent of external influences. In consequence of the continual excitement of the medulla oblongata by arterial blood, therefore, a periodic discharge of the nervous influence upon the nervous fibres alternately of the inspiratory and expiratory muscles takes place ; the excitement of one of these sets of muscles to action being followed, as a necessary consequence, by the antagonistic excitement of the other set. Irritation in the respiratory organs is capable of giving rise sometimes to a disturbance of this order of movements,—the irritation itself exciting movements by reflexion from the medulla oblongata ; thus, in cough, several expirations occur without each being preceded and induced by an inspiration. Other periodic inspiratory movements sometimes occur in certain states of the nervous system, namely, during fatigue, and in the state preceding and immediately succeeding sleep ;

such is yawning. Of similar nature are the periodic sighing and hiccough which attend certain nervous affections.

The respiratory movements are not the only periodic automatic muscular actions of daily occurrence which are due to the influence of the central organs of the nervous system. The motions of the muscles of the eye and of the iris during sleep present us with another example of these automatic muscular actions. During sleep the eye is turned somewhat inwards and upwards, and the iris is much contracted, although light is quite excluded. The eye takes this position even before sleep has come on; and the position of the double images which a person sees when he finds himself on the point of falling asleep, proves that the eyes are turned inwards. Their position is the same as that which they hold whenever the eyes are made to converge to a focus in front of any object; the image seen by the right eye lies to the right, that seen by the left eye to the left. It has been already shown that when the eye is directed inwards, whether voluntarily or involuntarily, the pupil is at the same time contracted. Both these phenomena are dependent on the action of the third nerve, and they both occur during sleep. The nervous principle, which in the waking state is expended on so many functions, is, in the production of these motions of the eye and iris, directed to a special region of the brain, and to the nerves which conduct the nervous influence to the muscles by which the motions are effected. It is possible, however, that the position which the eyes assume when sleep comes on, and the contracted state of the pupil during sleep, are merely the results of an antagonistic relation subsisting between the different branches of the third nerve; in consequence of which, the motions referred to necessarily take place whenever the levator palpebræ superioris ceases to act.

Automatic movements of the animal system with a persistent type. The sphincters of the animal system.—Although we have voluntary power over these muscles to strengthen their contraction, yet their action continues independently of volition during sleep as well as in the waking state, and it cannot be voluntarily interrupted, except by exerting a counter pressure against them by their antagonist muscles. The principal sphincters of the animal system are the sphincter ani and the sphincter vesicæ, which is to a certain extent subject to the animal system of nerves. The force and impulse to contraction of these muscles are derived from the spinal cord. Injuries of the spinal cord cause their permanent relaxation, and the consequent involuntary escape of the fæces and urine; this relaxation of the sphincters sometimes also occurs under the influence of depressing passions, which have the effect of weakening the power of the cord. Dr. Hall has shown that the sphincter ani of the turtle remains contracted as long, but only so long, as the lowest portion of the spinal cord is left uninjured.

The action of the sphincters must be owing to an incessant motor

excitement of their nerves. In considering the antagonistic muscular action, however, we shall become acquainted with facts which prove that not the sphincters alone, but indeed all the muscles of the animal system, are subject to this constant motor excitement.

We have thus seen involuntary movements partly of periodic character, partly persistent, which are dependent on the influence of the brain and spinal cord. The same phenomena are observed as symptoms of disease of the central organs of the nervous system; persistent as well as intermittent muscular spasms, muscular contractions often occurring at very regular intervals, involuntary motion of the head to and fro, trembling of the limbs and the tonic cramps returning at regular periods, are expressions of morbid states of those organs. It is not known why the motions assume these characters; it has been observed merely that the enduring contractions more generally attend the diseases of a completely local and fixed nature, although every kind of disease of these organs is capable of giving rise to periodic convulsive affections. As a general rule, indeed, nearly all affections of the nervous system which are attended with muscular contractions come on in paroxysms; and even inflammation of the spinal cord, though the cause has here a uniform action, gives rise to tetanic convulsions, which occur in paroxysms. These phenomena, together with the periodic character of the attacks of epilepsy, while the operation of their causes is constant, seem to show that the excitability of the nervous centres is exhausted by the constant impression of morbid irritation, just as the excitability of the nerves is temporarily lost under the influence of impressions which excite them, in consequence of the change produced in the nervous matter by the excitement, and that the power of reacting depends in both cases on the excitability being restored by rest. The fading away of the image of a coloured spot on which the eyes are long fixed, and its reappearance after an interval, and the periodic daily return of the states of sleep and waking in the sensorium, are phenomena which are typical of all such healthy or morbid periodic actions; for in these instances also the reaction ceases at intervals for a time, although the exciting impressions are constantly the same.

3. *Antagonistic movements.*

The action of muscles is not restricted to their occasional contraction when excited by discharges of nervous influence. There are grounds for believing that the muscular fibres, particularly those of the animal system of muscles, are constantly in a state of slight contraction, even during their apparent repose. The retraction of divided muscles in a living body, and, still more, the manifest contraction of muscles of which the antagonists are divided or paralysed, are in favour of this opinion.

When the muscles of one lateral half of the face are paralysed, those of the opposite half draw the features towards their side. The tongue, when one half of it is paralysed, is always drawn to the opposite side; and in cases of removal of the middle portion of the lower jaw, whereby the muscles which draw the os hyoides and tongue forwards,—namely, the anterior belly of the digastricus, the mylo-hyoideus, the genio-hyoideus, and the genio-glossus,—lose their fixed point of attachment, the os hyoides is drawn backwards by the stylo-hyoideus, and the tongue by the stylo-glossus, so forcibly, that great danger of suffocation arises. Hence it would appear that the state of inaction of the different parts of our body does not indicate an absolutely relaxed condition of the muscles, but rather that the different groups of muscles antagonise and balance each other; and that when the position of a part is changed from the medium state of apparent rest, one or more of the muscles, already in a state of antagonistic action, are merely thrown into more powerful contraction.

There are groups of muscles opposed to each other in their action in almost all parts of the body. The extremities have flexors and extensors, supinators and pronators, abductors and adductors, and rotators inwards and rotators outwards. Frequently the opposed groups of muscles have different nerves. Thus the flexors of the hand and fingers derive their nervous fibrils from the median and ulnar nerves; the extensors theirs from the radial nerve; the flexors of the fore-arm are supplied by the musculo-cutaneous; the extensors by the radial nerve. The crural nerve supplies the nervous fibres for the extensors of the leg; the ischiadic those for the flexors. The peroneal muscles, which raise the outer border of the foot, derive their nervous fibres from the peroneal nerve; the tibialis posticus, which raises the inner border of the foot, is supplied by the tibial nerve. The muscles which move the foot and toes backwards and downwards are supplied by the tibial nerve; those which move them in the opposite direction, by the peroneal nerve. The circumstance of the convulsive motions in affections of the spinal cord being frequently such as to curve the body in a particular direction,—a fact exemplified by the opisthotonus, emprosthotonus, and pleurotonus of traumatic tetanus,—shows that there must be something in the disposition of the nervous fibres in the central organs which facilitates the simultaneous incitement to action of particular sets of muscles, as the flexors or extensors, &c.; although Bellingeri's opinion that the anterior columns of the spinal cord serve for the motions of flexion, the posterior for those of extension, is based on no sufficient facts. Too much importance, however, must not be given to the above remark relative to distinct nerves supplying the different groups of muscles; it is not a constant fact. Sometimes the same nerve gives branches to muscles opposed in action; thus the ninth, or hypo-glossal nerve, supplies both the muscles which draw the hyoid bone forwards, and one muscle which retracts it; the peroneal nerve sup-

plies the peroneal muscles, which raise the outer border of the foot, and the tibialis anticus, which opposes this motion. Antagonist muscles can, moreover, be most easily made to combine in action; thus the peroneal muscles and the anterior tibial, acting together, raise the foot. The flexor carpi radialis and the extensores carpi radiales can combine so as to abduct the hand. The opinion of Ritter, that galvanism has different actions on the flexors and the extensors, has not been confirmed.

There are many muscles which have but few or no antagonists; such muscles always tend to give to the parts on which they act a determinate position. Thus there are numerous muscles which rotate the thigh outwards, while the rotation inwards can be effected but feebly by the tensor vaginæ femoris. Hence arises the involuntary tendency to the turning outwards of the whole limb in walking, sitting, or lying. The sphincters are also muscles which have no proper antagonists. The constant occlusion of the orifices of the viscera by the sphincters can be accounted for, therefore, solely by the fact of the contraction of muscles not wholly ceasing in the state of apparent rest, and of their having no antagonising muscles, without its being necessary to suppose that a constant current of nervous influence is transmitted specially to them. The sphincters give way when the contents of the bladder or rectum have accumulated, so as to excite a stronger contraction of the muscular coat of the viscus, which then impels these accumulated contents against the sphincter, and dilates it. The iris, which is also a sphincter, is constantly in the state of contraction during the waking state, and still more strongly so during sleep. During the act of awakening from sleep the pupil is seen to contract and dilate alternately, though the intensity of the light remains the same.*

The antagonism of muscular motions is of great pathological importance. Distortions are produced by the balance of the action of muscles being destroyed. Clubfoot, for example, which may take its rise during the first months of pregnancy as well as after birth, is frequently owing to the proper balance in the antagonistic action of the muscles which elevate the inner and outer borders of the foot being lost, and is often cured by restoring the balance of action. Either the peroneal muscles which elevate the outer border of the foot are partially paralysed, or the muscles which raise the inner border are in a state of "paralytic contraction." In either case the foot rests on its outer margin, and is drawn inwards by the tibialis posticus muscle. After a time, however, the position of the bones forming the joints is altered; the os naviculare is generally turned inwards, and the head of the astragalus, left partly exposed, forms a prominence on the dorsum of the foot. In pes equinus, in which the heel is drawn up and the foot rests on the toes, the gastrocnemii are tensely contracted, and nevertheless

* See Henle's article, "Gedächtniss," in the *Encyclop. Wörterb. d. Med. Wissenschaft*.

sometimes atrophied. A contracted state and atrophy of the muscles are not incompatible with each other. There is a kind of paralytic loss of power in muscles which is combined with contraction;* we have seen the gastrocnemii both contracted and atrophied at the same time.

Curvatures of the vertebral column certainly in many cases arise from scrofulous inflammation of the intervertebral ligaments and vertebræ, producing softening, enlargement, suppuration, and loss of substance, but still more frequently they are owing to loss of balance in the action of the muscles of the trunk. That the curvature is of the latter kind may be known by the absence of the signs indicating rachitis, and by the affection being benefited by gymnastic exercises. These spinal curvatures are, therefore, analogous to clubfoot and pes equinus. In tubercular suppuration of one lung, the thorax on that side is not elevated in respiration, because the lung is incapable of distension; the thoracic muscles of that side are not really paralysed.

4. *Movements arising from reflex nervous action.*

The nature of the reflected motions has been already fully investigated and explained. (See Book III. sect. III. cap. iii.) They include all muscular actions which arise from impressions on sensitive nerves exciting motor nerves to action through the intervention of the brain and spinal cord. They arrange themselves into two principal groups.

a. *Reflected motions of the animal system.*

These are the reflex motions of muscles which are under the influence of cerebro-spinal nerves; the impression which excites them may be made either on animal or on organic nerves; for example, in the skin or in the intestinal canal. Coughing from irritation of the mucous membrane of the lungs and larynx, vomiting from irritation of the mucous membrane of the pharynx, stomach, or intestine, and the contraction of the iris from irritation of the optic nerve, are examples of these reflex movements, of which we have described innumerable instances in the chapter on nervous reflexion, p. 706. These reflected motions of the voluntary muscles consequent on sensitive impressions are for the most part momentary muscular actions, or else persistent long-continued contractions. A high degree of irritation of the spinal cord by violent impressions on sensitive nerves sometimes, however, gives rise to rapidly-repeated rhythmic contractions of the muscles; such as we observe in the trembling excited by the application of a moxa, or when, from long exposure to a cold bath, the teeth chatter. The rhythmic contractions of the perinæal muscles from venereal excitement of the genitals, and the rhythmic expulsion of the semen by these muscles, afford, however, the most remarkable example of rhythmic reflected

* See Ollivier, *Traité de la Moëlle épinière et de ses Maladies*, t. ii. p. 709.

motions. They are the more remarkable, since the vesiculæ seminales appear to have, not a rhythmic, but a vermicular motion. The vesiculæ by this motion pour their contents in an uninterrupted stream into the urethra, along which they are afterwards impelled by the rhythmic contractions of the ejaculator muscle.

b. Reflected motions of the organic system.

The movements of the organic involuntary muscles under the influence of impressions propagated to the brain and spinal cord, whether from parts supplied by cerebro-spinal nerves, or from organs under the influence of organic nerves, have been considered at page 736. The motion of the heart can be affected by impressions made at any part of the body, the spinal cord being the medium of transmission of the influence. The various symptoms of fever are probably due to the impression communicated from some one organ to the spinal cord, and perhaps to the brain also, by organic nerves (see p. 808).

5. The associate or consensual movements.

These phenomena have already been considered generally, and their cause investigated (p. 683). Their peculiarity consists in the voluntary impulse to one motion giving rise to the production of other motions contrary to, or independently of, the will; thus, whenever the eye is voluntarily directed inwards, the iris contracts. The less perfect the action of the nervous system, the more frequently do associate motions occur. It is only by education that we acquire the power of confining the influence of volition in the production of voluntary motions to a certain number of nervous fibres issuing from the brain. An awkward person in performing one voluntary movement makes many others, which are produced involuntarily by consensual nervous action. In the piano-forte player we have an example, on the other hand, of the faculty of insulation of the nervous influence in its highest perfection. From the want of this faculty arises the absence of expression in the countenance of the uneducated; while on the perfection of this faculty depends in a great measure the defined character and expression of the features. The motions very prone to be associated involuntarily are those of the corresponding parts of the two sides of the body. The motions of the irides, of the muscles of the ear, of the eyelids, and of the extremities, in the attempt to effect opposed motions, are examples of such association (see p. 684).

Some of the most remarkable facts illustrating the association and antagonism of muscular actions are presented by the muscles which move the eyes. The corresponding branches of the third or motor oculi nerve of the two sides have a remarkable innate tendency to consensual action, a tendency which cannot be ascribed to habit. The

two eyes, whether moved upwards, downwards, or inwards, must always move together ; it is quite impossible to direct one eye upwards and the other downwards at the same time. This tendency to consensual motion is evidenced even from the time of birth ; it must, therefore, be owing to some peculiarity of structure at the origins of the two nerves. The association in action of the corresponding branches of the two *nervi motores oculi* renders the absence of such tendency to consensual motion in the two external recti muscles and the sixth nerves the more striking. We do, it is true, in a certain measure cause the two external recti muscles to act together when we restore the two eyes, of which the axes are converging, to the parallel direction : but there the power of consensual action ends ; the two eyes can never be made to diverge, however great the effort exerted to do so. The cause of this is not want of power in the external recti muscles ; nor is it their mode of insertion, which is the same as that of the other recti muscles ; neither does it arise from habit, for it is innate, like the tendency of the other recti to associate action :—the newly-born infant, though unable to fix the eyes on an object, can move them in any direction, except such as would make them diverge from each other. Moreover, the impossibility of directing the two eyes outwards at the same time cannot be owing to antagonistic action of the internal rectus, for either separately can perform that movement completely. In short, there is an innate tendency and irresistible impulse in the corresponding branches of the third nerve to associate action ; while in the sixth nerves not only is this tendency absent, but the strong action of one of these nerves is incompatible with the action of the other. These innate tendencies in the third and sixth nerves are extremely important for the function of vision : for if, in place of the sixth nerves, the external recti muscles had received each a branch of the third nerve, it would have been impossible to make one of these muscles act without the other ; one eye, for example, could not have been directed inwards while the other was directed outwards, so as to preserve the parallelism or convergence of their axes, but they would necessarily have diverged when one rectus externus had been made to act voluntarily. To render possible the motion of one eye inwards while the other is directed outwards, the external straight muscles have received nerves which have no tendency to consensual action. In consequence, however, of the tendency in the two internal straight muscles to associate motion, it is necessary, when one eye is directed inwards and the other outwards, that the contraction of the rectus externus of the latter should be so strong as to overcome the associate action of the rectus internus of the same eye ; and in the effort to direct one eye completely outwards we actually feel this stronger contraction of the external rectus. These considerations enable us to understand perfectly the hitherto enigma-

tical fact that in all vertebrata the external rectus muscle receives a special nerve.*

In the same way we may explain why the superior oblique muscle has received a special nerve (the fourth nerve or *n. trochlearis*), which likewise has no tendency to consensual action with the nerve of the other eye. It is necessary, however, first to determine the action of the oblique muscles. The inferior oblique moves the pupil inwards and upwards; this can be very easily demonstrated by laying bare the muscle from the front, the eye and orbit being undisturbed, and by then drawing the muscle towards its point of origin. The superior oblique muscle rolls the eye downwards and somewhat outwards. Sir C. Bell † has proved this by experiments on animals and on the dead human subject. I have satisfied myself of the correctness of his statements; I laid bare the superior oblique muscle from above without disturbing the parts, — without moving the eye from its cushion of fat, and then exerted traction on the muscle; the eye each time moved in the segment of a circle downwards and a little outwards. The outward motion effected by the superior oblique is much less than the inward motion produced by the contraction of the *obliquus inferior*. When both oblique muscles act together, or when traction is exerted on both in the direction of their origins at the same time, the eye is drawn forwards and the pupil directed inwards. The two superior oblique muscles have no tendency to associate motion with each other; the fourth nerve in this respect resembles the *nervus abducens* of the external rectus. When one eye is directed downwards and outwards, the other eye is not also directed downwards and outwards, but downwards and inwards; this is the case from birth upwards; it proves that the motion of the superior oblique of one eye through the influence of the *trochlearis* nerve is incompatible with the action of the corresponding nerve and muscle of the other eye. It is not so with the inferior oblique; the branch of the third or motor oculi nerve, by which it moves the eye upwards and inwards, has a tendency to consensual action with its fellow nerve of the opposite side; the motion of the eye upwards and inwards takes place therefore simultaneously on the two sides; it does so indeed involuntarily during sleep. This position, which the eye takes during sleep, and also in hysterical paroxysms, may be regarded as the effect of the simultaneous action of all the branches of the *nervus motor oculi*. Muscles, we have seen (page 925), are slightly contracted even in the state of rest; and, if we suppose all the branches of the motor oculi nerve to be in a state of slight excitement, both eyes would necessarily be turned upwards and inwards. The superior and the inferior rectus would balance each other's action; the internal rectus would draw the eye inwards, and the inferior

* Compare Jessen, *Beiträge z. Erkenntniss d. psychisch. Lebens*. 1831, 183.

† *Nervous System*, 8vo. 1824, p. 312.

oblique upwards and inwards; the corresponding branches of the third nerve which supplies these muscles being consensual in their action, both eyes would be simultaneously directed upwards and inwards.

Let us consider another effect which would have resulted if the rectus externus muscle had, in place of the sixth nerve, received a branch of the third nerve: had such been the case, the simultaneous direction of one eye upwards and inwards, and of the other upwards and outwards, which so often happens, would have been impossible. While the inferior oblique, and the simultaneous action of the superior and internal straight muscles, directed the one eye upwards and inwards, the same muscles, owing to the association of action, would have given the other eye the same direction; it could not have been directed upwards and outwards. Hence it was necessary that there should be a special nerve having no tendency to associate action with its fellow nerve, but capable, by the stronger contraction of the external rectus which it supplies, not only of preventing the second eye from being carried upwards and inwards by the inferior oblique and superior and internal straight muscles acting consensually with the same muscles of the first eye, but also, with the aid of the superior straight muscle, of carrying it upwards and outwards. The same remarks apply in the case of the motion of the one eye downwards and inwards, and of the other eye downwards and outwards. If one eye be turned downwards and inwards by the rectus inferior and the rectus internus, the other eye is turned downwards and outwards by the rectus inferior and rectus externus, aided by the obliquus superior, which being also supplied by a special nerve,—the fourth,—no tendency to consensual movement in the corresponding muscle of the opposite eye is excited. The fourth nerve—*nervus trochlearis*—belongs also to the nerves of expression.

The associate motion of the iris, when the motor oculi nerve is thrown into action, has been described and explained at page 684.

The organic muscles also are, in some measure, subject to the laws of association. At page 740, reasons are given for believing that the increased frequency and force of the heart's action during muscular exertions of the body is owing to this cause. The action of the voluntary muscles has an influence on that of the intestinal canal; neglect of bodily exertion is often productive of torpidity of the bowels; every one is aware how beneficial muscular exercise is in preserving the regularity of the muscular action of the intestines and regularity of excretion.

6. *Movements dependent on certain states of the mind.*

There are three classes of movements of this kind: 1, those dependent on mere ideas passing through the mind; 2, those arising from passions or the affections; and, 3, voluntary movements.

a. Movements excited by ideas.

Certain groups of muscles of the animal system are in a constant state of proneness to involuntary motion, owing to the susceptibility of their nerves, or rather the excitability of the parts of the brain from which they arise. This is the case with all the respiratory nerves, including the facial nerve. This excitability, this tendency to the discharge of nervous influence, is evidenced in the sneezing which occurs occasionally from internal causes; but the respiratory muscles may be excited to action merely by particular states of the mind. Any sudden change in the state of the mind is capable of causing these muscles to be excited to action. The sensorium acts here in the same way as an individual nerve in which any sudden change of condition of whatever kind sets the nervous principle in action. In this way we must explain the fact, that a sudden change of thoughts, such as occurs when the idea of the ridiculous arises in the mind, without any passion being excited, is capable of giving rise to an action of the nerves, which is evidenced in the muscles of the face and the respiratory muscles.

Yawning, inasmuch as it can be excited by the mere idea, or by seeing or hearing another yawn, belongs to the same class of movements. The disposition to the movements of the features and the respiratory muscles that constitute yawning, exists previously; and it becomes manifested when the idea gives to the nervous principle the determinate direction. The nerves engaged in the production of this movement also are the respiratory nerves and the facial nerve,—those branches of the facial which are distributed to the muscles of the face, as well as its branch to the digastric muscle. Ideas of fearful or detestable objects suddenly excited, even when called up by mere fictions, occasion in persons of excitable temperament the motion of shuddering; and the same occurs sometimes from the mere thought of a disgusting medicine: vomiting, indeed, may be produced by the mere recollection of a disagreeable taste.

b. Movements due to the passions of the mind.

It is principally the respiratory portion of the nervous system which is involuntarily excited to the production of muscular actions by passions of the mind. Here again we see that any sudden change in the state of the brain, propagated to the medulla oblongata, immediately causes a change of action in the respiratory muscles, through the medium of the respiratory nerves, including the respiratory nerve of the face. There are no data for either proving or refuting the hypothesis that the passions have their seat of action in a particular part of

the brain, whence their effects might emanate. But these effects are observed to be transmitted in all directions by the motor nervous fibres, which, according to the nature of the passion, are either excited or weakened in action, or completely paralysed for the time.

The exciting passions give rise to spasms, and frequently even to convulsive motions affecting the muscles supplied by the respiratory and facial nerves. Not only are the features distorted, but the actions of the respiratory muscles are so changed as to produce the movements of crying, sighing, and sobbing. Any passion of whatever nature, if of sufficient intensity, may give rise to crying and sobbing. Weeping may be produced by joy, pain, anger, or rage. During the sway of depressing passions, such as anxiety, fear, or terror, all the muscles of the body become relaxed,—the motor influence of the brain and spinal cord being depressed. The feet will not support the body, the features hang as without life, the eye is fixed, the look is completely vacant, and void of expression, the voice feeble or extinct. Frequently the state of the feelings under the influence of passion is of a mixed character; the mind is unable to free itself from the depressing idea; yet the effort to conquer this gives rise to an exciting action in the brain. In these mixed passions the expression of relaxation in certain muscles,—in the face, for example,—may be combined with the active state of others; so that the features are distorted, whether in consequence merely of the antagonising action of the opposite muscles being paralysed, or by a really convulsive contraction. Frequently also, both in the mixed and the depressing passions, some muscles of the face are affected with tremors. The voluntary motion of a muscle half-paralysed by the influence of passion is necessarily of a tremulous character, in consequence of its being no longer completely under the influence of the will. We experience this particularly in the muscles of the face when, during the sway of a depressing or mixed passion, we endeavour to excite them to voluntary action; the muscles of the organ of voice also, under such circumstances, tremble in their action, and the words attempted to be uttered are tremulous.

The nerve most prone to indicate the state of the mind during passions is the facial; it is the nerve of physiognomic expression, and its sphere of action becomes more and more limited in different animals, in proportion as the features lose their mobility and expressive character. In birds it has no influence on the expression of the face; those only of its branches exist which are distributed to the muscles of the *os hyoides* and to the cutaneous muscle of the neck; and the erection of the skin of the neck, or, in some birds, of the ear feathers, are in them the only movements by which the facial nerve serves to indicate the passions. Next to the facial, the respiratory nerves,—those of the internal organs of respiration, the laryngeal and phrenic nerves, as well as those of the

external thoracic and abdominal muscles, are most susceptible of the influence of the passions. But when the disturbance of the feelings is very intense, all the spinal nerves become affected to the extent of imperfect paralysis, or the excitement of trembling of the whole body.

The completely different expression of the features in different passions shows that, according to the kind of feeling excited, entirely different groups of the fibres of the facial nerve are acted on.* Of the cause of this we are quite ignorant.

[The disturbed action of the heart during mental emotions is a remarkable instance of the influence of the passions over the movements of organs supplied by the sympathetic nerve.]

c. Voluntary movements.

The cerebral and spinal nerves are alone capable of exciting voluntary motion. The history of cases of paralysis from disease of the spinal cord shows that the fibres of the spinal nerves are continued upwards to the medulla oblongata, and that the will has no direct action on them at any other part of their course than in the medulla oblongata, which is the source of all the voluntary movements. Again, the origin of the greater number of the cerebral nerves from that part of the nervous centres, and the possibility of tracing the roots of motor nerves apparently arising from other parts of the brain to the same point, as well as the history of lesions of the brain, prove that the cerebral motor nerves also receive their voluntary incitement to action from the medulla oblongata.

The fibres of all the motor, cerebral, and spinal nerves may be imagined as spread out in the medulla oblongata, and exposed to the influence of the will, like the keys of a piano-forte. The will acts only on this part of the nervous fibres; but the influence is communicated along the fibres by their action, just as an elastic cord vibrates in its whole length when struck at any one point. It is in the present state of our knowledge—and perhaps always will be—impossible to determine how by an exertion of the will in the medulla oblongata the nervous fibres are excited to action. All that we can do is, to consider the fact in its greatest simplicity.

A voluntary movement might be supposed to result from the intensity of the conceived idea respecting its object and the necessity of its immediate performance; so that, when the idea had reached a certain intensity, the movement necessary for the attainment of the object would necessarily ensue. Such a view is easily refuted; for in that case the rapidity of the movement would become greater as the

* On the imitative movements, consult Huschke, *Mimices et Physiognomices*, Fragment. *Physiol.* Jena, 1821.

intensity of the idea increased. It might further be imagined that a voluntary movement would take place whenever the sensorium is completely occupied by the idea of the immediate necessity of the movement for the attainment of a proposed object, and when this idea is neutralised by no other; there being but this one idea present in the sensorium. When I say, I will now do this or that, and nevertheless do it not, either merely the idea of willing it, and not the consciousness of the immediate necessity of the movement, is in my mind, or the fulfilment of that idea is neutralised by some other. But if we have an absolute certainty of the immediate necessity of a movement, and no other idea neutralises this, then, it might be supposed, the current or oscillation of the nervous principle necessary for the voluntary motion must inevitably ensue. According to this view, volition would consist in the mental equilibrium being disturbed by an idea of the absolute necessity of a movement, and the consequent nervous action in the medulla oblongata would be comparable to the sinking of one scale of a balance when its equilibrium is disturbed. It admits readily of proof, however, that the voluntary movements do not merely occur when the idea of the necessity of the particular movement is alone present in the mind; for we are able to continue for a long time simultaneously three or four different movements which have not the least connection. We read, sing, and play; or dissect and sing, and even smoke in addition, all at the same time.

It is evident also that the ultimate source of voluntary motion cannot depend on any conscious conception of its object; for voluntary motions are performed by the fœtus before any object can occur to the mind, before an idea can be possibly conceived of what the voluntary motion effects; we must therefore view the question in a much simpler manner. On what do the first voluntary movements in the fœtus depend? All the complex conditions which give rise to voluntary motions in the adult are here absent. Its own body is the sole world from which the obscure conceptions of the fœtus that excite its actions can be derived. The fœtus moves its limbs at first not for the attainment of any object, but solely because it can move them. Since, however, on this supposition there can be no particular reason for the movement of any one part, and the fœtus would have equal cause to move all its muscles at the same time, there must be something which determines this or that voluntary movement to be performed,—which incites the retraction, first of this foot or arm, and then of the other.

The knowledge of the changes of position which are produced by given movements is gained gradually, and only by means of the movements themselves; the first play of the will on single groups of the radicle motor fibres of the nerves in the medulla oblongata must therefore be independent of any aim towards change of position; it is a mere

play of volition, without any conception of the effects thereby produced in the limbs. This voluntary excitation of the origins of the nervous fibres without object gives rise to motions, changes of posture, and consequent sensations. The excitation of certain fibres produces constantly the same motions, the same changes of position, and the same sensations. Thus a connection is established in the yet void mind between certain sensations and certain motions. When subsequently a sensation is excited from without in any one part of the body, the mind will be already aware that the voluntary motion which is in consequence executed will manifest itself in the limb which was the seat of the sensation; the foetus in utero will move the limb that is pressed upon, and not all the limbs simultaneously. The voluntary movements of animals must be developed in the same manner. The bird which begins to sing, is necessitated by an instinct to excite the nerves of its laryngeal muscles to action; tones are thus produced. By the repetition of this blind exertion of volition, the bird at length learns to connect the kind of cause with the character of the effect produced. The instinct of this dream-like and involuntarily-acting impulse in the sensorium has some share in the production of certain movements in the human infant, which are in themselves voluntary. In the sensorium of the newly-born child there is a necessitating impulse to the motions of sucking; but the different parts of the act of sucking are themselves voluntary movements.* Hence we perceive that the voluntary excitement of the radicle motor fibres to action is an original innate power connected with the developement of the animal, and not dependent on a conceived object, as in the adult.

We have learned already from many other facts that the nervous principle in the medulla oblongata is in a state of extraordinary tension, or proneness to action; that the slightest change in its condition excites a discharge of nervous influence, as manifested in laughing, sneezing, sobbing, &c. While the tension of the nervous principle is not disturbed, we are equally ready to excite voluntary movements in any

* [Anencephalous infants, in whom no part of the brain but the medulla oblongata is present, have been observed to suck when the lips were touched by the finger or nipple; and Mr. Grainger (*Observations on the Spinal Cord*, p. 80,) has shown that the same thing occurs when the brain has been artificially removed; a young puppy, deprived of its brain, "on touching the mamma, threw up its nose, moved the mouth, trying to get hold of the nipple," and afterwards sucked the finger introduced into the mouth; in one experiment, Mr. Grainger mentions, that "as the puppy lay on its side sucking the finger, it pushed out its feet in the same manner as young pigs exert theirs against the sow's dugs." These movements, as well as those of deglutition and respiration, also presented by anencephalous foetuses, as well as the remarkable phenomena observed by M. Flourens in fowls after the removal of their brain (see pages 828 and 835), are evidently connected with an action of the medulla oblongata, and are considered by M. Müller as sufficient evidence of that part of the brain

part of the body, and such is the state of rest or inaction. Every mental impulse to motion disturbs the balance of this tension, and causes a discharge of nervous influence in a determinate direction,—that is, excites to action a certain number of the fibres of the motor nervous apparatus. The influence of the will on the fibres of the motor apparatus is not a solitary fact of its kind. There is in the central organs a power of voluntarily directing the mind to all the cerebral and spinal nerves, even to the nerves of common sensation, and the nerves of special sense. The phenomena showing this power are of importance with reference to the theory of the voluntary motions. The action of our organs of sense is usually accompanied by a constant concurrent action of the will. In regarding an object of complex figure, first one part is voluntarily impressed on our sensorium, then another; the effort of doing this is called “attention.” We are looking, for example, at an architectural rosette,—a polygon, the angles of which are connected by lines; the figure remains the same, but still we see first one part, then another part of it more distinctly than the rest; at one moment the periphery is seen most distinctly; at another, separate triangles: again, at another, quadrangular figures, which are contained within the whole polygon. We do this not merely by moving the eyes so as to follow or describe, as it were, the outline of the figure with the axis of vision; but, the direction of the eyes remaining the same, the different parts of the figure are in succession impressed, by an effort of the attention, more distinctly on the sensorium, while the other parts are still perceived, but not attended to. In the organ of hearing it is still more evident that the modification of the impressions on the sense by attention does not depend on muscular motions. During the performance of an entire orchestra, we are seldom so passive as to perceive all the tones which strike the ear simultaneously, with a distinctness merely proportioned to their own intensity. On the contrary, by our faculty of attention we are able to follow the tones of a weaker instrument among the louder sounds of the others, which are disregarded for the time. If two persons are addressing different words to our opposite ears,

being the seat of volition; while other physiologists, as Mr. Grainger and Dr. Hall, regard all these phenomena, together with the movements of the fœtus in utero, as resulting from reflex nervous action. Some of the phenomena presented by the fowl deprived of its cerebrum can with difficulty be believed to result from reflex motor action independently of volition; but the argument which Professor Müller draws from pathology in favour of the medulla oblongata being the seat of the will appears to be imperfect. Lesions of the spinal cord below the medulla oblongata will, it is true, prevent the transmission of the influence of the will to parts supplied by nerves arising below the seat of the lesion, and disease of the medulla oblongata will affect also the action of cerebral nerves; but disease much higher in the brain, as in the optic thalamus or corpus striatum, is also productive of paralysis both of the cerebral and spinal nerves, when the medulla oblongata is apparently in a perfectly healthy condition.]

we can by attention follow what is said by the one, while we leave what the other says unnoticed. The same circumstance is observed in the case of simultaneous impressions on different senses. According to the direction we give our attention we cease to see distinctly, while we exert the power of hearing to a greater degree, and *vice versâ*; for only one object at a time can be taken cognizance of by the faculty of attention.

This analysis of the impressions made by objects on the senses is frequently performed quite involuntarily, in accordance with the laws of the association of ideas. But we have also the power of directing the attention according to our will. Thus, in the above examples, it depends entirely on our own choice what parts of the architectural rosette we should regard most accurately, of which instrument of an orchestra we should follow the tones, and to which of two persons speaking at the same time we should listen. In short, the will has here the same influence as in the production of voluntary motions. The only difference is, that in the latter case the motor nervous fibres previously in a state of repose are excited to action, while in perceiving the impressions on the senses the action of the will consists merely in rendering the sensation more intense or distinct.

The power of the will is not limited, however, to the motor and sensitive nerves; it also influences the mental operations. Our faculty of conceiving ideas, the imagination, acts, it is true, independently of the will, as in dreams; and in the state of waking, though we cannot produce with closed eyes illuminated images similar to those excited by the imagination in dreams, yet we have the power of voluntarily directing our thoughts. In short, we see that the voluntary effort of the sensorium can be directed upon motor or sensitive nerves, or made to affect the mental operations; an act of volition is nothing else than the voluntary and conscious direction of the nervous principle in the brain upon different cerebral apparatus; and on the part of the brain subjected to this voluntary action of the nervous principle depends, whether the effect shall be a muscular movement, a more distinct perception, or an idea.

The regulation of the quantity of nervous influence expended in voluntary motion, or the strength of the nervous action and of the muscular movement, are dependent on the same causes as the localization of the voluntary movement. Both the one and the other have determinate limits. Though the exertion of many muscles at the same time sooner exhausts the strength, yet it is most easy for the will to determine whole groups of muscles to action; and as a general rule, it may be affirmed that a voluntary movement is more difficult the smaller the number of nervous fibres required to be excited, and the smaller the part to be moved. The nervous principle much more readily excites

many than few nervous fibres to action; hence the tendency to the associate movements described at page 928. It is very doubtful whether distinct portions of a long muscle can be voluntarily excited to independent and separate action. The action of the nervous principle is here evidently shown to be less capable of localization when excited by volition than when determined by accidental involuntary stimuli. From internal causes independent of the will, very small parts of a muscle,—for example, of the biceps of the arm,—are seen to contract separately. This never occurs from voluntary influence. The power of confining the voluntary excitement of the nervous principle to distinct groups of fibres is increased by much exercise, and the more frequently certain groups of fibres are excited to action by the influence of the will, the more capable do they become of isolated action; this is exemplified in performers on the piano-forte, &c. The movement of the same muscles when frequently repeated becomes difficult, however, after a time; this is intelligible on the principle that, although action alternating with rest increases power, yet any continued exertion of a vital property induces temporary exhaustion, in consequence of which the organ, whether a muscle and motor nerve, or an organ of sense, becomes for a time incapable of action (see page 52, *et seq.*)

The problem,—wherefore are the muscular parts supplied by the sympathetic nerve not subject to the will, except by association with voluntary muscles supplied by cerebro-spinal nerves? has been discussed at page 739.

Motions very frequently performed occur at last whenever the nervous influence in the brain receives in the slightest degree the direction necessary to produce them; hence frequently the mimic movements of the hands in speaking. This also shows that the conducting power of the nervous fibres increases with the frequency of their excitement. From this cause it is that obscure ideas, without any distinct consciousness, often give rise to perfectly determinate and appropriate motions, provided these motions have been previously many times excited in the same manner.

CHAPTER II.

OF THE COMPOUND VOLUNTARY MOVEMENTS.

By the compound voluntary movements we understand all combinations of movements in determinate groups, which the mind has a share in producing. The kinds of motion treated of in the preceding chapter may enter as elements into the composition of these combined movements. We have here to consider the simultaneous series of voluntary movements consequent on several series of ideas, the associations of movements, and of ideas with movements, the instinctive movements, and the movements of locomotion.

a. Simultaneous series of movements.

Not only can motion be determined voluntarily for a given object in very different parts of the body at the same time; but voluntary movements for very different objects can likewise be simultaneously performed. It is easy to write and smoke at the same time; a performer on a musical instrument reads the notes both of the song and the accompaniment, calling the muscles of the eyes into action for this purpose, and sings and plays simultaneously. How shall we explain the simultaneous occurrence of all these actions? Can we really follow at the same moment different series of ideas which have no connection with each other? or can but one idea be conceived at the same time; and is the complicated action of reading notes, singing, and playing, apparently at the same time, produced by a constant rapid transferring of the agency of the mind from one of those series of acts to another? The first thing to be ascertained is, whether the mind can in any case follow two series of ideas simultaneously. If this is possible, the appropriate movements corresponding to each series of ideas may also be produced. The voluntary motion of different motor apparatus,—for example, of the muscles of the voice and fingers,—at the same time, is not difficult of explanation; for it matters not whether several muscles moved simultaneously be situated in one and the same limb, or be very distant from each other: in both cases the action of the nervous principle is directed upon a certain sum of radicle nervous fibres. The difficulty consists in determining whether the two series of ideas which are the causes of the excitement of the nervous fibres can subsist at the same time. For the closer examination of this question we have a simple example in a person who, while walking, is engaged in an active train of reflection on some perfectly independent subject. We determine to visit some person; on our way we are so busied in other thoughts that we neither remark whom we meet, nor notice those who greet us; and, nevertheless, we arrive at the place that we had intended. During our immersion in a particular train of thought, we still followed the series of images excited in our sensorium by the houses and streets, through which we found our way almost unconscious of what house we were seeking.

The best example, however, for the solution of this problem, is afforded by persons learning particular movements. The motions are here so slow, and their combination so difficult and ill-executed, that we are able to watch the operations of nature in them. When a learner on the guitar or piano-forte attempts to sing and play at the same time, it is at once evident that he is unable to read the note of the song and those of the accompaniment simultaneously. The note for the voice is

perhaps rightly conceived and would be sung; but the note for the piano is still wanting, and the instrument halts; and *vice versâ*. This arises, not so much from the difficulty of reading, as from the inability of converting what is read into ideas for exciting the movements. Each note is converted in our sensorium into an incitement to motion for the muscle of this or that finger, or for a muscle of the larynx; and in addition to these two simultaneous series of transpositions, by which notes of music being read are converted into incitements to motion, there is a third accompanying them, by which words read afford incitements for the motion of the organs of speech. In the last operation there is no difficulty, since we are exercised in it from youth upwards; but the incitement of certain muscles of the fingers, or certain muscles of the larynx, to action in accordance with the printed notes of music, requires practice. From the above example we learn clearly that the voluntary movements dependent on several different ideas can be executed simultaneously, but that they cannot be simultaneously conceived in the mind. Even the practised performer reads, although almost with the rapidity of lightning, first the notes for the voice, then those for the instrument; the idea of their proportional time is thus obtained, and the corresponding incitements to motion being formed from them in the sensorium, the movements are then executed simultaneously. It might be objected that, since for giving a different duration to the movements corresponding to two different notes a perfect recollection of their value is required, while at the same time the sensorium would be already occupied with the succeeding notes,—since, therefore, the sensorium is able to retain two different ideas in the memory, and at the same time conceive a third,—the simultaneous conception of several series of movements dependent on different ideas must also be possible. The validity of this objection is, however, only apparent; for the prolongation of a movement in accordance with the value of a note requires no action of the sensorium; for every movement is here continued until it is interrupted by the incitement of a new motion required by another note. The simultaneous performance of the most different movements is, we repeat, attended with no difficulty, for it is as easy to move the muscles of the larynx and those of the fingers at the same time, as to move several of the muscles of the arm simultaneously; but the conception of these different movements from different series of ideas can take place, it appears, only successively, though their succession may be as rapid as the lightning-flash. We now return to the consideration of the case before alluded to. We pass in deep thought through many winding streets to the house of a friend; we are so absorbed that on our way we observe nothing; we forget to greet friends, and do not notice those who greet us; and at last we arrive at the desired place without knowing how we came there. The

voluntary locomotion, this constantly exercised alternation of flexion and extension of the limbs being a simple periodic repetition of two movements, can as easily as a single movement when once commenced be continued uninterruptedly at the same time with a constant succession of thoughts. It is more difficult to comprehend how we can find our way through the numerous windings of the streets, and at the same time follow an internal train of thought. It may, however, be very well explained, on the supposition of the attention being diverted at short intervals alternately from the one theme to the other. The laws of the association of ideas are in many ways engaged in this action. If two series of ideas of equally little interest present themselves to the mind, the attention can be directed alternately to the one or the other with the greatest facility, or may be diverted from these altogether by a third train of ideas. But if one series of ideas is predominant in the sensorium, as in a state of passionate excitement, any new idea excited through the medium of the senses may for a moment interrupt the ruling train of thought; but the sensorium always returns to the original theme more readily than it is diverted from it to remote associations.

b. Association of movements and ideas.

The rapidity and easy succession of movements is promoted by their frequent repetition. This is what we call practice. A person who is not practised cannot, in a constant rapid change, interrupt and again renew the same movement, or execute complex movements with regularity. The effect of practice shows that the more frequently the same fibres are thrown into action, the easier does their action become.*

We have to consider this kind of association in two points of view.

1. Association of movements with movements. Hitherto the involuntary consensual or associate movements have been frequently confounded with the voluntary associated movements. The former depend on the influence voluntarily directed in the sensorium to the excitement of one nerve extending involuntarily to another. Thus one eye cannot be voluntarily raised without the other being also raised involuntarily. Such phenomena are not the result of practice; their cause is innate. They are observed to the greatest extent in the persons least practised; and the object of practice, and the education of the muscular move-

* The laws of the association of voluntary movements have been so frequently explained, that they are now very generally recognised, even in writings on practical medicine. The phenomena of association have been studied more especially by Darwin, and are described in his *Zoonomia*, vol. i. Compare also Reil, *Fieberlehre*, iv. p. 609; Reil, *von der Lebenskraft*; Reil's *Archiv*. i.; and Brandis, *Versuch über die Lebenskraft*. Hannover, 1795.

ments, consist partly in learning to confine the action excited by the will to single groups of nervous fibres. The result of exercise or practice with respect to these movements is therefore the diminution of the tendency to the involuntary association. It is quite otherwise with the association of voluntary movements. Here practice develops in the muscles the capability for rapid succession or simultaneous execution of movements, when the muscles as yet have but little proneness to such association. The effect of practice is, therefore, in this case, the very reverse of its result in the case of the involuntary associate movements. Practice diminishes or annuls the innate tendency to involuntary association of movements, while it renders the voluntary association of several muscles in action more easy. Darwin and Reil have in some parts of their writings confounded these very different conditions of the nervous system. The law laid down by Darwin* is, that "all the fibrous motions, whether muscular or sensual, which are frequently brought into action together, either in combined tribes or in successive trains, become so connected by habit, that when one of them is reproduced the others have a tendency to succeed or accompany it." This may be granted generally; but the examples chosen by Darwin and Reil to illustrate this law are in part instances of the involuntary associate or consensual movements. Moreover, the law proposed by Darwin does not describe the facts quite correctly; for, were they as this expresses them, education and practice would only render us less expert in our movements. The associate movements taught us by practice would be frequently an inconvenience, a hinderance to our actions, instead of practice removing the innate tendency to involuntary association of movements, which is really the case. The example adduced by Darwin and Reil, that we cannot easily cut the air horizontally with one arm and move the other in a circle, does not illustrate the association of voluntary movements arising from practice; for this tendency to a similar movement of the two arms is innate, like that which regulates the movements of the eyes. On the contrary, practice gives us the power of executing the dissimilar movements of corresponding parts of the two sides. Another example mentioned by Darwin and Reil is a better illustration of the association of voluntary movements. A person learning to use the turning-lathe at first determines every new direction of his chisel by previous thought; after a time, his will seems to be seated at the point of his instrument. Here by practice the muscular movements are associated in quick voluntary succession; one movement is not the cause of the other occurring, but their rapid combination is rendered more easy; and such is the case in all association of voluntary movements. When movements have been frequently associated in certain orders of succession, the difficulty of

* *Zoonomia*, p. 49.

thus associating them becomes constantly less, so that the will is then able to produce the whole series very rapidly, without, however, one of the movements composing the series taking place involuntarily. Facts, however, do not appear to me to warrant Reil's statement that the will, by determining one of the movements, can give rise to the whole series. There are, it is true, many movements due solely to habit, which are repeated on the least occasion, such as the unmeaning waving of the arms in actors and singers, and the movement of the hands in most persons of lively temperament; but these movements of habit do not belong to the association of voluntary movements with each other, but to the association of movements with ideas.

2. Association of ideas and movements.—The connection between ideas and movements is sometimes as close as that between different ideas; thus, when an idea and a movement have frequently occurred in connection with each other, the idea often excites the involuntary production of the movement. Hence it is that a threatening movement before the eyes, even the passing of another person's hand in front of them, causes the eyelids to be involuntarily closed; that we are accustomed always to accompany the expression of certain ideas with certain gestures, and that we involuntarily move our hands to catch a falling body. It is a general rule that the more frequently ideas and movements are voluntarily associated together, the more prone are the movements to be excited by those ideas rather than by the will, or to be withdrawn from the influence of the will. This kind of association plays as important a part as the association of movements with each other in the production of mechanical dexterity and perfection in the mechanical arts. The association of movements with each other can only be accounted for on the supposition of a more ready path being developed in the brain for the communication of nervous influence in a certain direction, and the concatenation of ideas and movements seems to indicate that every idea in the mind gives rise to a tendency to action in the nervous apparatus of the movement which expresses that idea, and that this tendency to action is by practice and habit so exaggerated that the mere disposition which exists in ordinary cases becomes, each time that the idea occurs, a real action. Yawning may serve as an example of this. If the disposition to yawn exists, the mere idea of yawning often excites the act. What connection subsists between the image in the sensorium of a person yawning and the involuntary movement thus induced? Whence arises it that among so many countless ideas formed in the sensorium this one only of the movements of a person yawning excites the act? The fact clearly proves that the idea of a movement alone suffices to produce a tendency to it in the apparatus by which it is effected. I have on another occasion remarked that the spectators of a fencing-match, or combat with swords, accompany

the blows of the combatants with slight involuntary movements of their body. A similar fact may be observed on a bowling-green. From the same cause, we experience, when in a dangerous situation on considerable eminences, a kind of propensity to precipitate ourselves down the height. The propensity to the imitation of movements is of the same nature. When we wish to look grave, and continue to think of laughing, we are obliged ultimately to laugh; like children, who look one another in the face to see which laughs first. Frequently, long after a ridiculous circumstance has occurred, an observer bursts into laughter from seeing others concealing or suppressing a laugh. Lastly, the occurrence of a paroxysm of convulsions in patients subject to them when they see others so affected, is another example of the association of movements with ideas. In hospitals, when several persons liable to convulsions lie in the same ward, the occurrence of a paroxysm in one sometimes excites the same in others.

M. Chevreul has explained the tendency to movements excited by the idea of the movement, and illustrated it by a complicated case, that, namely, of the vibrations of a pendulum held in the hand. The movement of the pendulum while the arm remains fixed is, according to his researches, effected by a slight muscular movement of which the individual is unconscious; this movement, he says, ensues involuntarily when the person looks at the pendulum which he is holding, but does not take place when the eyes are bound. The two principal facts here are, that a pendulum held in the hand can be set in motion by a muscular action so slight that the individual remains unconscious of it; and that looking at the motion once produced gives rise involuntarily to a series of muscular actions calculated to increase the motion, the mind remaining unconscious of this action of the muscles. M. Chevreul made application of this fact to the explanation of yawning also.* M. Behn† has, however, shown that one of the chief causes of the continued agitation of the pendulum held in the hand is the slight motion imparted to all parts of our body by the arterial pulse.

The association of movements with certain ideas is not an isolated fact of its kind, even if we do not take into account the frequent association of ideas with each other. Ideas do not act merely on the motor apparatus by which they are expressed; they as frequently affect the organs of sense, which then present sensorial impressions or images of the ideas. There is a great difference between the idea of a disgusting sensation and the sensation of disgust itself, and nevertheless the mere idea of a nauseous taste can excite the sensation even to the production of vomiting. The quality of the sensation is a property of the sensitive nerve, which is here excited without any external agent. The mere sight of a person about to pass a sharp instrument over glass or

* Forriep's Notiz, N. 831.

† Müller's Archiv. 1835.

porcelain is sufficient, as Darwin remarks, to excite the well-known sensation in the teeth. The mere thinking of objects capable when present of exciting shuddering, is sufficient to produce that sensation of the surface in irritable habits. The special properties of the higher senses, sight and hearing, are rarely thus excited in the waking state, but very frequently in sleep and dreams; for, that the images of dreams are really seen, and not merely present in the imagination, any one may satisfy himself in his own person by accustoming himself regularly to open his eyes when waking after a dream. The images seen in the dream are then sometimes still visible, and can be observed to disappear gradually. This was remarked by Spinoza, and I have convinced myself of it in my own person.*

c. Instinctive movements.

The combined movements, of which the nature is most obscure, are incontestably the instinctive. All those acts of animals are instinctive, which, though performed voluntarily, do not nevertheless depend primarily on the mere will of the animal, which have an object according with the wants of the organism but unknown to the animal, and of which the hidden cause, acting in accordance with the design of the system, incites the animal to the necessary acts by presenting to its sensorium the "theme" of the voluntary movements to be executed in detail by the influence of the will. When incited by instinct, we are conscious only of feelings and impulses to determinate acts. And these instinctive impulses in the human subject are few; the impulse to the movements of sucking in the infant is an instance. The acts which lead to the exercise of the sexual impulse are in animals generally excited by instinct; in man this is certainly only in part the case. Even admitting the embrace of forms which excite the feeling of love to be the result of an impulse implanted in us, the first of our race undoubtedly learnt the rest by experience. The number of the instinctive acts is great in animals in proportion to their incapability of accomplishing the design for which their species was created by their mental powers. This is not the place to recount the great number of the instinctive acts connected with the migration of animals, the construction of nests and dwellings, the formation of webs, and the rearing of young.

The cause of instinct appears to be the same power as that on which the first production of the animal, and the perfection of its organisation in unison with an eternal law, depend.† The instinctive acts of animals

* See Gruithuisen, Beiträge zur Physiognosie u. Eantognosie. München, 1812; and J. Müller, über die phantastischen Gesichts erscheinungen. Coblenz, 1826. This subject will come under consideration again in the Sixth Book, on the mental faculties.

† The attributes of the creative organic force or power have been considered at pages 22 to 25.

show us that this power, which, independent of any organ, forms the whole organisation with reference to a determinate purpose and in accordance with an unchanging law, has moreover an action beyond this; they prove that it influences the voluntary movements. That which is effected by the instinctive movements is equally in accordance with a determinate purpose, and as necessary for the existence of the genus and species as the organisation itself; but while, in the case of the organisation of the being, the object attained formed part of the organism, in the case of the instinctive movement it is something in the exterior world; the mental power of the animal is incited by the organic creative force to conceive, and to attempt to attain, some special object. The primary cause of instinct is therefore not seated in any one organ, but is identical with the creative force of the organisation, the operations of which are guided by an unvarying law and a rational principle. The influence of this force in the production of instinct is, however, first manifested in the sensorium. The expression of Cuvier with reference to instinct is very correct. He says, that animals in their acts of instinct are impelled by an innate idea,—as it were, by a dream.

It is further to be remarked that the realisation of the ideas, images, and impulses, thus developed in the sensorium, is admirably facilitated by the organisation of the animals. Both the internal impulse and the external organisation being dependent on the same original cause, the form of the animal appears in complete unison with its impulses to action; it wills to do nothing which its organs do not enable it to effect, and its organs are not such as to prompt to any act to which it is not impelled by an instinct. The mole, impelled by its internal instinct to a subterranean life, has an indistinct sight, (from the smallness of the eyes and from their being surrounded with thick hairs,) not fitted for other habits; and its fore-feet and legs are not only entirely formed for burrowing, but the way in which the fore-foot is articulated to the fore-arm is such that it can scarcely walk without burrowing. The extremities of the sloth again are constructed for climbing and living in trees, in which indeed they pass the night; and while their movements on the ground are extremely slow and awkward, their toes being turned inwards and their feet resting on the outer border, in trees they are very expert and powerful, though slow in their motions, like other climbing animals,—for example, the chameleon.

It is a subject full of wonder to observe how instinct imparts to animals faculties, capabilities, and intuitive perceptions, which we acquire only by the laborious process of experience and education. When we first see, we are unable to judge of the distance or nearness of objects, the images of which are formed in our eyes. All objects in the field of vision being depicted on a surface—as in painting, it requires long ex-

perience, and the aid of touch and voluntary movements, to enable us to attach to the image of an object in the field of vision ideas of its distance, size, and form. Animals appear, when born, as if they had been already submitted to this education. The calf soon after birth runs to the mother's teat. The human infant does not learn to go alone until after laborious practice, in which the laws of equilibrium and gravity, &c. must every moment be attended to, and until the degree of contraction of the muscles necessary for each movement has been learnt by experience and previous errors. The young of animals—at least, of the solidungula and ruminantia,—are born with the knowledge of these things. They soon after birth rise on their legs, and run to the mother to suck. This must be the result of the operation of the instinctive power which resolves all the problems of physics. In the sensorium of the newly-born animal there must be a power at work which directs the proper action of the levers of the locomotive members.

From the acts due to instinct, we must distinguish certain others which many animals are able to perform with great precision even during sleep after they have by previous practice gradually acquired the necessary ability. Many birds sleep standing upon one leg. They preserve their equilibrium with the greatest certainty, and there is no rest to the force exerted in these acts, though the sensorial operations of the sensorium be quite suspended. Sleep-walking is a similar phenomenon. It is not instinct that leads the somnambulist, but the faculty of walking safely acquired by experience, which faculty he continues to exercise even during sleep. All the knowledge acquired by education and experience with reference to maintaining his balance is put in practice; it is by the operation of his mind alone, and not by instinct, that he is prevented from falling: but his sensorium is active in one direction only, and in no others; and the circumstance of his being, in consequence of this limited action of his faculties, ignorant of danger, renders him secure, and carries him safely past precipices. These phenomena are indeed not so difficult of explanation as at first sight appears. The security with which a person walks over a moderately sloping surface depends entirely on his knowing that it is not at a great elevation. The same sloping surface on a steep hill appears dangerous and difficult to ascend; and provided a person does not see any danger in the last case, he will pass over the ascent as securely as if it were at a little distance only from the surface of the earth.

Since in animals there are evidently instinctive innate feelings and perceptions, which manifest themselves immediately after birth or at a later period, it becomes a question whether man also has not innate ideas which exert on him in a higher grade the same coercive power which the instinctive impulses and feelings of animals exercise over them. We shall return to this question in the part of the work which

treats of the functions of the mind. Hopes have been indulged that the instinctive rational operation of the organising force might in certain states make us conscious of what we could not learn by our mental faculties. There is no ground for such hope; and I am not aware that the power of nature, which is quietly at work in the human system, ruling and creating the organisation independently of the mental consciousness, though in accordance truly with a rational and higher law, has ever communicated any knowledge to the mind, or that the divine reasoning spirit (of Spinoza), which has a creative power, has ever mingled itself with the images of objects conceived by our mind. The phenomena of this kind, reported to have occurred in the pretended magnetic states, are undeserving of the belief which credulous medical men have accorded to them; and they have in too many cases proved to be the result of deception or folly. The disclosures made in the magnetic state have been nothing more than products of the imagination, often indeed very confused, and of a nature appropriate to the capacity of the person affording them, and of the believing listeners.

d. Co-ordinate movements.

Although the movements of locomotion are dependent on the will, the appropriate combination of the separate muscular acts necessary for them appears, nevertheless, to be rendered more easy by some internal disposition of the nervous system, and there seems to subsist between the nervous centres, the groups of muscles and their nerves, a harmony of action dependent on original structure. This idea is suggested by the experiments on the functions of the cerebellum and the spinal cord. Decapitated birds are seen to make all kinds of attempts at locomotion. The same has been observed in frogs. Although they have not the character of voluntary movements directed by the influence of the brain, still there prevails a certain unison between the different acts of such tumultuous movements observed in geese after decapitation. They beat the ground with their wings, a movement for which the simultaneous and concordant action of many nervous fibres is necessary; and it appears, therefore, that there is some organic arrangement in the central organs which favours the co-ordinate action of certain nervous fibres. The movements of the decapitated bird are not mere spasmodic contractions of all the muscles subject to the influence of the spinal cord; for, were all the nervous fibres arising from the divided cord thrown into a state of irritation, all the muscles of the body would be equally excited to contraction; flapping of the wings would not be thus produced: at all events, it is not easy to conceive why the wings should not on the contrary be folded spasmodically close to the body. The twisting motion of eels, and the flapping of the tail in other fishes, after their head is cut off, are phenomena of the same kind. Invertebrate animals perform

the movements of locomotion after decapitation, sometimes quite in the ordinary manner. The influence of the will, indeed, seems in them still to be exerted. (See page 793.)

The experiments of M. Flourens, moreover, show that there exists not merely in the spinal cord a provision for the performance of certain groups of movements in unison, but that the cerebellum more especially rules over the combination of the muscular actions required for locomotion (see pages 831—835). Injuries of the cerebral hemispheres, or their removal, did not deprive the animals of the power of executing combined movements. But the removal of the cerebellum produced not merely weakness, but loss of all harmony in the action of the groups of muscles. M. Flourens, however, observed that the bird, when laid on its back after the extirpation of the cerebellum, fluttered its wings; showing some slight remains of the power of co-ordination, which, as we see in geese after decapitation, may be derived from the spinal cord. This co-ordination of movements must be of great use to animals in the first employment of their extremities, which they are observed to move so aptly; the co-ordinate movements are indeed much engaged in the production of all the instinctive acts. In the act of sucking, an internal incitement to the necessary co-ordinate movements exists in the brain. Even the head of a decapitated kitten still performs the movements of sucking, as Professor Mayer has observed, when the finger is held in the mouth.*

CHAPTER III.

OF THE MOVEMENTS OF LOCOMOTION.†

Many animals are for the most part destitute of locomotion, and are only capable of a relative movement of particular parts with reference to the rest of the body. Some of these animals are fixed by one part of their body; others lie free.

The compound entozoa are in the first-mentioned condition; in the *Cœnurus cerebralis*, for example, the only motion of the separate animals united by a common vesicle consists in their elevating themselves above

* [Admitting that the act of sucking is, as was maintained by Sir G. Blane, and more recently by Mr. Grainger and Dr. Hall, (see note to page 936,) the result of reflex nervous action excited by the external stimulus of the nipple or finger, it would still afford the same evidence of the existence of a provision for the combination of certain movements in the nervous centres.]

† [Even the movements of locomotion are supposed by Mr. Grainger (On the spinal cord, p. 93—116) to be in some measure the result of reflex nervous action. He seems to think that the continuance of our movements of walking, for example, while the mind is abstracted, is owing to the propagation to the spinal cord of the impressions produced by the contact of the soles of our feet with the ground. His chief grounds

the surface of this vesicle, and their subsequent retraction. The compound polypes, again, are capable of no other locomotion than the protusion of the head of the separate polype and its arms, and the retraction of them again into the polype-cell. Even the *Pennatulæ*, which were long believed to be free, and to move about in the sea, are fixed to the bottom like the *Veretilla*; the separate polypes only of these compound animals have motion. External influences excite the retraction of those polypes only on which they act directly.* Rapp, however, has observed a slow bending motion in the stem of the *Veretillum*. In what relation the independent movements of the separate polypes stand to these slow contortions of the stem in *Veretillum*, is not at present quite clear; indeed, the nature of the physiological connection between the polypes and their stem is a most difficult problem to solve.†

A part of the arm-polypes are capable of free locomotion, as the *Hydra*; a part are fixed, as the *Coryne*. There are some of the *Annelida* which have no free locomotion; for example, the *Serpulæ*, which inhabit calcareous tubes. The tubuli-branchiate gasteropods, as the *Vermetus* and *Siliquaria*, live in fixed tubes. The *Ostracea* (the oysters and allied bivalves) are in part fixed by their shell to rocks; others of them are free; but in either case they scarcely at all change their place, their movements being limited to the closing of their shell, which is opened by an elastic ligament: again, others of this family, as the *Pinnæ*, fix themselves to solid bodies by means of the byssus issuing from the rudiment of the foot, this byssus being their anchor, as *Cuvier* expresses it. The *Mytilus*, or sea-mussel, family, also employ

for this opinion are, that the motions excited by irritating the skin in decapitated animals resemble those performed in locomotion, and that the movements produced in paralysed limbs by irritating their surface (see note * p. 721), occur most readily, and are most energetic, when the sole of the foot, which in walking comes to the ground, is the part to which the irritation is applied. Mr. Grainger attributes great importance to the fact that the reflex movements of paralysed limbs are excited more readily and in a more marked degree through the medium of the sole, than by irritating any other part of the foot or leg where the skin is thinner; and remarks that the most sensitive parts are not the most excitable. But in the instance in question, the degree of excitability is directly in accordance with the sensibility of the parts; for on reference to page 701, it will be seen that according to the investigation of Professor E. H. Weber, the points of a pair of compasses applied to the skin of the dorsum of the foot or leg, cannot be felt as two distinct bodies until they are separated to the extent of eighteen lines, while, on the plantar surface of the metatarsal bone of the great toe, they can be distinguished at the distance of seven lines. Hence we see that the greater excitability of the sole of the foot than other parts of the limb will afford no ground of argument for the existence of special excitomotory fibres distinct from the sensitive fibres.]

* Rapp, über die Polypen, S. 8. On the structure of the stem of the polype, and on the currents observed in it, see Rapp, loc. cit. and *Nov. Act. t. xiv. pt. 2. p. 650*; Lister, *Philos. Trans.* 1835, pt. 2; and Meyen, *Nov. Act. t. xvi. Suppl.*

† See Ehrenberg, *Die Corallenthiere des rothen Meeres.* Berlin, 1834, p. 27.

their long foot more for the attachment of the byssus than for locomotion. Other allied conchifera, as the *Anodon* and *Unio*, (fresh-water mussels,) creep along the bottom by means of the foot. The *Ascidia* are attached to rocks, and are destitute of all locomotion. Their voluntary movements consist solely in the spirting of water from the mouth of the mantle, which is adapted for that act. Of the compound *Ascidia*, the *Botrylli* are fixed to foreign bodies, and are united, several in the form of a star; and Cuvier remarks that, if the oral orifice of a single animal be irritated, this one animal only contracts; but that if the common cavity in the centre of the star be touched, they all contract. The *Pyrosoma*, belonging to the same group of mollusca, is a compound animal, of which the individuals are so united as to form a hollow cylinder, into which the anal aperture of each opens. They are free, and are said to swim about by the combined contractions of all the individuals forming the compound animal.* The details of this phenomenon, which is so remarkable in a physiological point of view, are not known. The disappearance of the phosphorescence when any one part of the cylinder is injured, is certainly in favour of there being a community of action in these creatures. The compound polypes present us no instance of a condition so extraordinary.

Many animals belonging to very different classes are free during one part of their life, and fixed at another.—Some are first fixed, and afterwards free: of this, the *Vorticellæ*, according to Ehrenberg, afford us an example. Others are free during the earlier stage of their life, and afterwards become fixed, and destitute of all locomotion; of which remarkable circumstance, the interesting observations of Von Nordmann † respecting the *Lernææ*, of Dugès ‡ respecting the *Hydrachnida*, and of Burmeister § on the *Cirrhopoda*, present us with examples.

Animals endowed with locomotion.—The organs of motion in animals capable of changing their situation are sometimes cilia, bristles, laminae, or fins, sometimes articulated members. In other cases the movement is effected by the expulsion of fluids previously taken in; by undulatory movements of the different parts of the body, which are in turn fixed, drawn after other parts, or stretched forwards; or by the alternate dilatation and contraction of the whole body.

Professor Ehrenberg || has minutely described the organs of locomotion in the *infusory animalcules*. The more simple of the locomotive organs in these creatures are either processes capable of undergoing great changes, which can be protruded from different parts of the body, as in the genus *Proteus*, or *Amæba* of Ehrenberg; bristles, as on the

* Cuvier, Règne Animal.

† Micrographische Beiträge.

‡ Ann. d. Sc. Nat. 1834.

§ Beiträge zur Naturgeschichte der Rankenfüßer. Berlin, 1834.

|| Zur Erkenntniß der Organisation in der Richtung des kleinsten Raumes. Berlin, 1832, p. 28.

back of *Chætonotus*; cilia, which in the polygastric infusoria frequently occupy the whole surface; or, in other instances, hooks. The more complicated organs are the rotatory apparatus of the wheel-animalcules and some of the polygastrica. Ehrenberg has described several varieties in their forms; what he has discovered of their structure has been detailed at page 860. The vibrations of the cilia of the rotatory organs serve not merely to produce currents in the water for the attraction of nutriment, but also to carry the animal through the fluid. The wheel-animalcule, however, is also able to creep over surfaces, by fixing alternately the anterior and posterior extremities of its body, the posterior extremity being drawn up towards the anterior, and this then stretched further forwards.

Acalephæ, that have a disc or bell-shape, change their place by the alternate contractions and expansions of their body, by which the water contained in the cavity of the bell is expelled. Others of the *Acalephæ*, the *Beroë* for example, move in part by means of vibrating laminae arranged along the eight costæ of their globular body. Some other *Acalephæ*, as the *Diphyidia*, have tubular swimming cavities, which act as the bell-shaped cavity of the *Medusæ*; in others there is an air-bladder, by means of which they keep themselves at the surface of the sea. In the *Physalia* there is, besides this great air-bladder, a part acting like a sail,—a membranous crest which can be filled with air, but which can also be emptied again. The air-vesicle has an opening at each end, closed by a sphincter.*

Echinodermata.—The *Holothuria* can propel itself by the expulsion of the water taken into its respiratory organs (fig. 18, p. 297); its whole body is capable of being shortened by strong longitudinal muscles. But the *Holothuriæ*, like the allied families of *Asterias* and *Echinus*, possess, moreover, the system of water-tubes discovered by Tiedemann; these tubes, communicating on the one hand with a contractile reservoir, terminate on the other hand in the hollow feet of the animals, which are protruded by being injected with the fluid, and are retracted by virtue of their own contractility.†

The *Annelida* which are not fixed swim through the water by undulatory movements of their body. The *Salpæ* and allied *Tunicata* move by taking in water by the posterior opening of the mantle, where there is a valve, and expelling it by the opening which is near the mouth. The creeping of worms (*terrestrial annelida*) and caterpillars (*larvæ of insects*) over solid bodies is thus effected: aliquot points of their body being fixed, others are drawn after them, when the extremity of the part last moved being fixed, the parts in front, which formed an arch, are stretched farther forwards. The means of attachment are some-

* Eschscholtz, Syst. d. *Acalephen*. Berlin.

† Tiedemann, Anat. der Röhrenholothurie, &c.

times the parts about the mouth; sometimes feet, as in the caterpillars; sometimes suckers, as in leeches, &c. In other annelida, and in the mollusca generally, the movement of creeping results from the alternate contractions and dilatations of the body or of the foot. The earth-worm does not creep like the leech by bringing its body into an arched form and then elongating it; but a certain number of segments of their ringed body are fixed, and the segments succeeding each one that is fixed are simply drawn towards it, diminishing the length, but increasing the breadth of this portion of the body; the posterior extremity of the part thus drawn together is then fixed, and the shortened part contracts transversely, so as to extend itself forwards; this kind of motion exists in the leeches also. In the *gasteropod mollusca* (snails, &c.) this movement takes place in so many separate points at the same time, that, when we observe a snail crawling on a plate of glass, the appearance presented is only that of a succession of very minute undulations, while the snail itself appears to move on uninterruptedly. A similar succession of undulations is seen in the foot of the Lymnææ (fresh-water snails) when they lie on their back, hanging, as it were, at the surface of the water. It is difficult to understand how separate points of a surface so smooth as the foot of the snail can in this way take fixed attachments.

Mechanism of locomotion.—The essential principle of locomotion in its most different forms, swimming, crawling, walking, or flying, and in almost all animals, is, that parts of their body form arches, which in straightening themselves act against a fixed point of resistance. In some cases the arches are formed by the whole worm-like body, as in the crawling and swimming of some animals; in other instances, in place of the arching and straightening of the body, the same is effected by the approximation and separation of the two sides of an angle; in which case one of the sides or branches of the angle, by the resistance it meets with from a solid or fluid substance, affords the fixed point which enables the separation of the two branches or opening of the angle to carry the other parts of the animal forwards. This is the principle of movement in animals with locomotive members, whether these be fins, wings, or legs, and whether they move in water, in the air, or on the ground: for even the air and the water afford resistance to bodies which strive to displace them; and the force exerted in displacing them reacts, in proportion to the resistance they give, on the body of the animal, and imparts to it a motor impulse in a determinate direction. In connection with this subject, the laws of the action of levers must necessarily be considered. Although many varieties of the lever are met with in the limbs of animals, yet they are for the most part so applied that power is lost; thus the muscles in many, indeed in most cases, act on them in an oblique direction, and are besides inserted very frequently near the

fulcrum, and distant from the moving end of the lever. There are more important objects thus attained than mere beauty of form. Had nature in every limb adopted the arrangement of lever calculated to give the most power, such a complexity, angularity, and awkwardness of form would have resulted, that the increase of impediments to a harmonious co-operation of parts would have caused the expenditure of force to be in the end even greater than it now is. Extent of motion also required that the muscles should not be inserted far from the fulcrum of the lever: for had their insertion been placed nearer the moving extremity of the lever, power would, it is true, have been saved; but, on account of the slight degree of shortening of which muscles are capable, (according to M. Schwann's experiments, at most a third of their length,) extent of motion would have been lost,—the biceps, for example, would not have been able to bring the fore-arm close to the arm, which it can do in consequence of being inserted near the fulcrum. [Velocity of motion, also, as well as extent, is gained by this mode of insertion of muscles, for in the same time that the part of the lever immediately acted on passes through a small space, the other end, far removed from the fulcrum and moving force, traverses a much greater space, and moves with proportionate rapidity.]*

Swimming.†—Both in swimming and in flying, the medium which affords the resistance, is also that in which the animal moves. In walking and crawling, whether in the water or in the air, the water and air are passed through; but a solid body, the earth, affords the support for the propulsion of the centre of gravity. In swimming and flying, therefore, the medium which serves as the fulcrum for the motion is yielding; while in walking and springing it is solid. The greater the force with which the locomotive organs press upon the air or water in proportion to the mass of the body to be moved, and the resistance offered to its passage through the medium, so much the greater is the motion produced. By resistance is meant here the loss of motor power which a body forcing its way through a fluid medium experiences in displacing the particles of the fluid.

In swimming, the essential act consists in the straightening of an arch which in becoming straight exerts pressure on the water. If we suppose a flexible and elastic rod of the same size throughout lying in the water to become bent in the middle, and then straightened, the two halves of the arch would strike the water in the oblique direction with equal force, and the straightened rod would not be impelled forwards in

* On the movements of locomotion, consult Borelli, *de motu Animalium*. Lugd. Batav. 1685. 4.—Barthez, *Neue Mechanik der willkührlichen Bewegungen des Menschen und der Thiere*. Halle, 1800. 8.

† Borelli, *loc. cit.*—Muncke, in *Gehler's Physikalisches Wörterbuch*.

the longitudinal direction. The result is the same when two levers of equal size united by a hinge are inclined towards each other and then extended, the mass of the two levers being the same; the power at their middle, which effects their approximation, will move each with equal force towards the other, and a force acting at the same part in such a manner as to extend the joint will move them with equal force from each other. But if the principal mass of the body form one of the levers, the force acting at the point of flexion will tend rather to move the smaller lever towards the larger one than this towards the smaller. While the larger lever will preserve its position in the water, the smaller one, both in flexion and extension, will alter its relative position to the larger mass. This is what takes place both in the boat propelled by a sculling-oar at the stern, and in the fish. In both, while lying in the water, the force exerted to change the relative position of the sculling-oar or tail, and the principal mass, to each other, moves primarily only the smaller part,—namely, the oar or tail, towards the body of the boat or fish. When, however, the oar is again brought to a straight line, it exerts a pressure upon the water behind it; and, were this water a solid body which could not be displaced, the boat would be impelled with the whole force with which the oar is moved, in the contrary direction,—namely, obliquely forwards. The pressure of the oar, however, imparts to the water a part of its own motor force, causing it to be displaced; the rest of the force with which the oar is moved tends to separate the water acted on, and the mass of the boat, from each other, and the latter is in consequence propelled obliquely forwards. The movement of the oar in the opposite direction gives to the boat an impulse obliquely forwards towards the contrary side; and a quick succession of such movements imparts to the vessel the middle straight direction. It is necessary, preparatory to each new stroke, that the oar be again brought from the straight line to an angle with the body of the boat, and since the water is thus acted on in the opposite direction, the propulsive force imparted to the boat would be neutralised, were this movement of the oar made with equal force with the former; for, in fact, an oar moved from side to side in the water with equal force in both directions gives no motion to the boat.

The motion of a fish in swimming is exactly similar to that of a boat propelled simply by the movement of the sculling-oar at the stern; the tail of the fish is the sculling-oar. Two strokes of the tail in quick succession are in many fishes with a short tail, as the carp, sufficient to give the fish the middle direction. It is frequently observable, however, that the fish, while swimming slowly, does not follow a straight course, but moves alternately from side to side in an oblique direction, in accordance with alternate strokes of the tail towards either side. Fishes with a long tail can form it into two arches looking in contrary

directions, which they straighten at the same moment, thus impelling the body in a straight line forwards. The flat-fishes (plaice, turbot, and flounders,) and the cetacea strike the water with their tail in the perpendicular direction. The rays swim partly by means of their tail, which they use like most other fishes; their thoracic fins, however, are extended out on each side like wings, and they act in swimming in a similar manner to the wings of birds in flying. In all other fishes the fins have a very subordinate share in the production of the principal movements of swimming; this was proved by Borelli.* The fins serve like feet, by their pressure on the water, to preserve the position of the fish's body, and to steady its motion. Cuvier attributes to them the office, also, of producing the movements of the fishes to the side; but for this, as we see in the carp, the one-sided movement of the tail is much more effective.

Quadrupeds in swimming use their feet as oars, in the same way that boats are moved by oars. The resistance of the water displaced by the oar is the cause of the boat being propelled forwards, while the angle between the oars and boat enlarges. If the oar were moved backwards and forwards in the water with the same force and in the same position both ways, the boat would not be moved. The movement of the boat in one direction depends on the oar being brought back after each stroke through the air, or, if not, with the edge instead of the broad surface to the water. The same principle is observed in the swimming of animals by means of their feet. The hands and feet are brought back after each stroke in such a position as to press with a smaller surface on the water. A man in swimming brings his arms forward to the proper position with the cutting border of the fingers foremost, and then strikes the water with the flat surface of his hand. The quadrupeds which have not broad flat feet, as the horse, also propel themselves forwards by striking the water with a larger surface than they oppose to it in restoring their limbs to the position for the succeeding stroke; in the backward motion of their legs they act on the water with a much larger surface than when they bring them forwards again. Quadrupeds are for the most part swimmers by nature, since they use their limbs in the water nearly in the same manner as in moving on land; and the length of their nostrils, and smallness of their cranium, enable them to make the opening for respiration the highest part above the surface of the water. In man, the only position in which the opening into the respiratory organs is highest, is that in which he lies in the water on his back; man, too, before he can swim, must learn a particular movement of the limbs, to which he is previously unaccustomed,—such a movement, namely, that the legs and arms, in being brought forward for each new stroke, present a less surface to the water than in the back-

* Borelli, loc. cit. p. 257.

ward motion. The practised swimmer is able to float on the surface of the water with very little other movement than that of inspiration; he is supported at the surface as long as his lungs, distended with air, render him lighter than water. Like quadrupeds, man is naturally heavier than water; and he sinks in it, if he make no effort, as soon as he expires the air from his lungs. But while his chest is well filled with air, and his body extended on the back, he keeps at the surface. If we did not require to expire,—were we able to keep the chest constantly distended without changing the air,—we might remain quite motionless, without sinking; but, in consequence of the body sinking at each expiration, it is necessary to counteract this tendency by motion of the hands. Birds are kept at the surface of the water in consequence of the air being received into large cells in the abdomen and into the bones through communications with the lungs. Before diving, birds require to make a strong expiration. Swimming birds use their feet as oars; swans use also their extended wings as sails to move along the surface of the water.

The air-bladder of many fishes, which, according to Von Baer's observations,* is developed, like the lungs, from the pharynx, facilitates their movement in the upper regions of the water, and, by the compressibility of the air it contains, enables the fishes to move in different depths according to the degree of pressure exerted by the lateral muscles of the body upon it. By reason of its position at the upper part of the abdominal cavity, where, owing to the large size of the dorsal and lateral muscles, the centre of gravity would otherwise be situated, this organ also serves to keep the back of the fish uppermost in the water, although it is not indispensably necessary for this purpose. Fishes in which the air-bladder has been ruptured do not afterwards rise to the surface, and are liable to fall upon the side.

Flight.†—The flight of birds is effected by the action of the anterior extremities, spread out horizontally to their utmost extent, upon the air, which reacting by its resistance and elasticity, the body of the animal is raised. This movement requires great strength of the pectoral muscles, and a modified structure of the thorax; the dorsal vertebræ, namely, do not admit of motion; the central piece of the sternum is developed so as to give space for the attachment of the large pectoral muscles; while the articulation of the humerus is strengthened not merely by the strong clavicles, but also by the furculum uniting the two shoulder-joints. The wings are folded so as to offer less resistance to the air before they are raised for a new stroke; when raised, they are

* See Müller's Archiv. 1835, p. 234.

† Borelli, loc. cit.—Cuvier, Anat. Comp. t. i.—Fuss, Nov. Act. soc. sc. Petrop. xv. 1806.—Silberschlag, Schriften der Berlin, Gesellschaft Naturf. Freunde, 1784. 11.—Horner, in Gehler's Physikal. Wörterbuch, iv. p. 477.

again spread out. The carpal articulation in the wing of the bird is not capable of flexion and extension; the wing when expanded is on this account stiff, and better calculated to act against the resistance of the air; the only movement of the carpal joint is adduction and abduction, by which the carpus and metacarpus can be folded down to the fore-arm or separated from it. A succession of strokes of the wings when they are quite horizontal carries the bird perpendicularly upwards in the air, as we see larks ascend. When the wings are inclined so that their under surface looks backward, their action must cause the bird to ascend obliquely, whereupon it will descend in the same oblique direction; and a regularly repeated action of wings thus inclined will produce a horizontal flight in an undulating line. The motion of the wings themselves need not partake much of the horizontal direction; for, even when the stroke of the wing is perpendicular, the flexible feathers yielding to the resistance of the air must immediately render the surface of the wing oblique from the posterior border downwards towards the anterior fixed border. This circumstance was pointed out by Borelli. An alteration in the direction of the flight towards either side is effected by the unequal vibration of the two wings, and not by a lateral inclination of the tail; for pigeons deprived of the tail feathers can still wheel round in the air. By bending the tail, the posterior part of the body is raised, the anterior part depressed.

The immobility of the back in birds gives to the trunk, the lower part of which is the seat of the centre of gravity, the solidity required to support the vibratory motions of the wings; the tapering pointed head is well adapted to divide readily the air; and the long neck, by being retracted or extended, gives a means of altering the position of the centre of gravity. The large expanse of the wing is not formed solely by the feathers; for the skin itself extends as a fold between the anterior border of the arm and the fore-arm, and, when the wing is expanded, is stretched out by a special muscle—*extensor plicæ alaris*. In the anterior border of this fold there is an elastic band which in the intervals of flight draws the fore-arm towards the arm. The *extensor plicæ alaris* has a double tendon, of which one portion of a fibrous nature is connected with the *musculus radialis externus longus*, and the *fascia antibrachii*; the other is the elastic band in the anterior border of the fold, already mentioned, which goes to be attached to the carpus and metacarpus.* The birds of the ostrich family, *Struthionidæ*,—the *Struthio camelus* (ostrich), *Rhea Americana*, *Casuarus Indicus* (cassowary), and *Dromaius Novæ Hollandiæ* (emeu),—and some water-birds, as the *Aptenodytes* and *Alca* (penguins and awks), are, on account of the small size of their wings, incapable of flying.

* Lauth, *Mém. de la Soc. d'Hist. Nat. de Strasb.* t. i.

The air in the bones of birds is evidently intended to render them lighter than they would be, were they filled with marrow. But the inflation of the air-sacs which communicate with the lungs cannot make the bird really specifically lighter, since the air in these sacs must have nearly the same density as the atmosphere. [The great heat of the bird's body must, however, in some measure rarefy the air within it.]

In many insects the injection of air into the tracheæ ramifying in the wings, which at other times are folded together, appears to contribute to maintain them extended and stiff.

In other classes besides birds, there are animals which can fly, or at least keep themselves suspended some little time in the air by means either of wing-like membranes or long fins. The order "Cheiroptera" (the bats), among mammalia, have their anterior extremities perfectly adapted for flying. The surface destined to strike the air is here formed by a membrane which extends between the elongated phalanges of the four fingers and metacarpal bones, stretches across the angle between the arm and fore-arm, and is continued from the elongated bones of the arm along the side of the body to the hind-feet, and from these even to the tail. This membrane of the bat also contains elastic tissue. The extinct reptile, *Pterodactylus*, was a true volant; the outer finger only, however, was in this animal much elongated for the purpose of flight; the other four were short, and armed with claws, like the thumb of the bat.

Other animals belonging to different classes have a membrane extending between their digits, which are short and all furnished with claws, between the arm and fore-arm, and between the arms and legs; but this membrane serves merely as a "parachute," as, for example, in the flying-cat (*Galeopithecus*). The cutaneous expansion between the anterior and posterior extremities of the flying-squirrel (*Pteromys*), and of the flying phalangiers (*Petaurus*), and the fold of skin expanded between the lengthened posterior ribs of the reptiles with parachute (*Draco volans*), are of similar nature and purpose.

Some fishes (*Dactylopterus* and *Exocætus*) are enabled, by means of their elongated pectoral fins, to raise themselves above the surface of the water for a short space.

Crawling or creeping. — Both in crawling and in walking, a solid body affords the point of resistance. There is no essential difference between these movements, except that, in walking, special extremities are used both to support and to propel onwards the weight of the body; while, in crawling, the same objects are effected by aliquot parts of the vermiform body itself. In walking, angles formed by the legs are widened and contracted; in crawling, the vermiform body of the animal is alternately arched and straightened. Both movements can be per-

formed in the water as well as in the air, a solid body always giving the points of resistance. Crawling can be performed in very different modes. The kind of crawling most similar to walking is that in which two points of the body only are applied to the resisting surface, while the rest of it is raised in an arched form; this mode of crawling is observed in the leech. In others of the annelida, the same movement takes place in many different parts of the body simultaneously, as in the earth-worm and caterpillars, and sometimes in the leech. This last kind of crawling is most remarkable in the snail (see page 953); and since, though able to crawl over very smooth surfaces—such as glass, it has no other instruments for attachment and support which are necessary to enable the animal to move in a particular direction, it is probable that the foot takes points of attachment by elevating and thus exhausting different points along its surface in succession; this action of the sucker being transmitted from one part to another during the movement of crawling.

The crawling of snakes is very peculiar; the body moving forward constantly and rapidly in a horizontal undulating line, which line every point of the body follows. The points of support and resistance against the ground are taken by the extremities of the ribs aided by the abdominal plates; while the parts situated behind each point of support are drawn towards it, and others pushed forwards.

Walking and running.—In swimming, the body is borne up wholly or in part by the water, and its motor power is nearly entirely expended in the act of propulsion. In flying, the body is not supported by the medium in which it moves, and a certain additional amount of force is required to neutralise the tendency to fall after each act of propulsion. In walking, the body is both supported and moved forwards by its own strength; and there is this peculiarity, that the body in this movement is alternately supported on each extremity which is fixed on the ground, while by the other it is propelled forwards. One half of this movement is represented in a boat moved on the water by a pole pushed against the bottom; but what the water effects in supporting the boat is done by the other extremity in the act of walking in the air. In leaping, in which the body for a short space of time is kept suspended in the air by the propulsive force imparted to it, the second act of the movement—that of supporting the weight of the body—does not take place till the spring is completed. In this case, as in flying, the body is kept up by the same movement that propels it forwards; the medium serving for the point of resistance is, however, different, namely a solid body. After the influence of one movement of the wings in flying has ceased, the bird is prevented from falling by a new movement of propulsion; at the end of the movement of leaping, the body is prevented from falling by supporting itself on a solid surface.

The means by which these movements are performed in the human subject, is the extension of two joints flexed in opposite directions, namely, the ankle and knee-joints. By this act of one extremity the centre of gravity is carried forwards, while the weight of the body is supported towards the end of the movement by the second extremity. The two extremities alternately support and move the body. The movement of propulsion being exerted, not in the middle line, but by both extremities at the side, the extension of the joints gives an impulse not merely forwards, but towards the opposite side. The arm of the side on which the extremity is being extended is each time thrown forwards.

The researches of Dr. Eduard Weber concerning the articulations,* and those of MM. E. and W. Weber respecting the movements of walking and running, have made us acquainted with many remarkable facts of a physical nature relating to these movements of locomotion, and with their laws. The physiology of these movements has first received a scientific accuracy from their discoveries. The most important facts which they have established are the following, which I extract from their work.† In the first place, and as a key to many other remarkable facts, we must mention the discovery of Dr. Eduard Weber, that the head of the thigh-bone cannot be separated by the mere weight of the limb from the surface of the articular cavity to which it is accurately adapted; but that, in all its motions, it is retained close to the articular surface by the pressure of the atmosphere. All the muscles which surround the hip-joint may be divided, but the weight of the limb does not remove the head of the bone from its cavity. If, however, the pressure of the atmosphere be allowed to act from the cavity of the joint on the head of the bone, by a hole being bored from the cavity of the pelvis into the acetabulum, the head of the femur immediately falls out of its socket.

The three physiologists named above have confirmed this discovery by means of the air-pump. The experiments were performed in the presence of Professor Magnus and myself. The hip-joint of a subject was dissected clean from the surrounding parts, the thigh-bone was sawn across below the trochanters, and the capsular ligament then carefully laid open all round; a weight of two pounds was attached to the remaining portion of the femur, and the whole hip-joint then placed in the bell of an air-pump. By the time the air in the bell had been so far rarefied that its pressure was equal to one inch only of the mercurial column, the head descended pretty rapidly seven lines from the articular cavity, without, however, escaping from the cartilaginous rim; when the air was again admitted to the bell of the air-pump, the head of the bone rapidly ascended again. Even when the head of the bone had

* Müller's Archiv. 1836, p. 54.

† Mechanik der menschlichen Gehewerkzeuge, mit 17 taf. Gött. 1836-8.

been forcibly removed from the articular cavity, if it were replaced so as to expel all the air from the cavity of the joint, it retained its position firmly, and could be with difficulty removed by traction in the perpendicular direction. The joint being again exposed to the vacuum of the air-pump, the same phenomena occurred as before; but now the bone fell entirely out of the articular cavity, when the pressure of the air was reduced to one inch. The influence of the atmosphere appears to be the same in all joints of this kind. It results from this important discovery of M. Weber, that the extremity freely suspended is maintained in its relation to the joint, in all the movements of rotation, by the atmospheric pressure; and, therefore, that the mere relaxation of the muscles cannot give rise to a separation of the head of the bone from the articular cavity. In ascending very high mountains, where the air is greatly rarefied, the muscular force must on that account become more necessary to maintain the articular heads of bones in their proper cavities, and the peculiar kind of fatigue which has been experienced by persons passing over high mountains is probably attributable to this cause.

MM. E. and W. Weber have further pointed out the importance of the pendulum-like oscillations of the legs in walking. If the body be supported on one leg upon a raised pediment, the other leg, being set in motion, will vibrate backwards and forwards like a pendulum. These vibrations may also be produced, if, while standing with one leg upon a level surface, the other leg be bent to such a degree as not to strike the ground in its vibrations. The time of these vibrations, like that of the vibrations of a pendulum, depends on the length of the limb and on the mode of distribution of its weight. Thus, in persons with short legs, the vibrations are quicker than in those with long legs; but, in the same person, the number of oscillations within a certain period are always the same. This property of the legs, and the circumstance that each step of the foot previously extended behind the body commences with a pendulum-like oscillation, give to our steps the greatest regularity, even at times when our attention is not directed to the movements of our limbs. The leg, while moving with the pendulum-like oscillation, is somewhat flexed, that it may not strike the ground.

The general mechanism of walking is as follows:—The body is supported by the two legs alternately, and the moment in which each forms the support is immediately succeeded by that in which the heel of the same limb is elevated and the body impelled forward by it. At the time that the foot A gives this movement of impulsion, the body is supported by the leg B, which, however, during the movement of the body forwards in an oblique direction, and while the leg A makes the pendulum-like movement forwards for the new step, proceeds to elongate itself by raising the sole of the foot from the ground, in order to give the body a fresh

impulse. The extremity A now becomes the support for the body. The MM. Weber compare the gradual raising of the soles of the feet from the ground to a wheel rolling along the surface. By this movement the step is lengthened by the whole length of the foot. In every step we may distinguish two periods; one in which the body is supported by one leg only, and a shorter period in which both legs rest on the ground. It is only in very quick walking, which nearly amounts to running, that the feet only touch the ground alternately, one ceasing to support the body when the other begins to receive its weight. In ordinary walking there is between the periods in which the body rests on one leg only, a state of transition, which lasts from the moment when the front foot is put to the ground, and that at which the hind foot is quite raised from it. According to the MM. Weber, this period is in slow walking about half as long as that during which the body rests on one leg. The quicker the walk, the shorter is this period.

The trunk is inclined forwards in walking. This position is necessary for walking easily; it is impossible to move forwards a rod balanced perpendicularly on the fingers, without its falling. To walk with the body perpendicular, it would be necessary to exert a constant muscular effort to restore the balance disturbed by the resistance of the atmosphere. In quick walking the trunk is more inclined forwards, while there is only a very short, if any period, at which both feet rest simultaneously upon the ground; and the steps are both longer and quicker. The condition on which all these circumstances in quick walking depend is, as MM. Weber show, the less height at which the two heads of the thigh-bones are moved above the surface of the ground. When the level at which the hip-joints are carried is low, the steps are longer, because the leg with which the step is to be made can be moved farther from the vertical position when its upper extremity is low than when it is high. The step, moreover, is quicker under these circumstances; for, the lower the level at which the head of the femur is carried in walking, the greater is the inclination of the leg which gives the impulse to the body, and hence the greater also is the force and velocity of the movement it imparts. With regard to the number of steps made in a given time, this depends partly on the length of the leg which swings from behind forwards, and partly on the time at which this motion of the limb is interrupted by the foot being put to the ground. The longer the leg, the slower are its oscillations,—that is, if the movement of the limb be not accelerated by muscular effort. Hence, abstraction being made of this power of voluntarily accelerating the movement, there is in every individual a certain maximum of the number of the steps taken in a given time, which cannot with ease be exceeded. This maximum rate of walking without great effort is attained when the limb moving from behind forwards is brought to the ground, after it has already

passed through half the extent of its natural oscillation. But the succession of the steps can be rendered slower by allowing the leg to pass through more than half its arc of oscillation before putting it to the ground.

It necessarily follows, from the nature of the movements of walking, that the body must, at each impulse forwards, rise somewhat and then sink again. These vertical undulations are, however, on account of the legs being capable of elongation and shortening, very slight, amounting, according to MM. Weber, to only 32 millimetres (about 1 inch $3\frac{1}{4}$ lines). The movement of the arms backwards and forwards always takes place in the opposite direction to that of the leg of the same side. The leg, by acting against the ground so as to propel the body forwards, gives an impulse to the whole trunk, which might be expected to cause the opposite leg and both arms to fall forwards. But while the leg of the opposite side, and the arm on the same side with the limb which gives the impulse, move forward, the other arm is thrown backwards. This order of the movements of the limbs, which is maintained so habitually that it is practised without our consciousness, contributes not a little to the preservation of the good carriage and equilibrium of the body. On each side, namely, one limb is thrown forward at the same time; on one side an arm, and on the other a leg; and in this way the defects of movement in the trunk which might be produced by the swinging of the leg from behind forward are corrected.

The circumstance characteristic of running is, that only one leg comes to the ground at a time, while in walking there is a period at which both feet rest on the ground. In quick running, indeed, the body is at one moment of each act supported by neither leg, but is moved through the air for a short space of time by the impulse communicated to it.

The locomotion of quadrupeds on the surface of the ground is performed, generally, on the same principles as the walking and running of man; but it presents a greater number of modifications, which have reference either to the part of the extremity which is put to the ground, or to the order of succession or simultaneous occurrence of the actions of the different limbs. Many animals, as the quadrumana (monkeys), and plantigrade carnivora (bear, racoon, and coati), rest upon the whole sole of the foot. In the marsupial animals (kangaroo, opossum, &c.) the carpus is raised from the ground; the digitigrade carnivora and the rodentia tread wholly on the toes; and the feline family of digitigrade carnivora rest upon the first two phalanges, the last phalanx which supports the claw being retracted by an elastic ligament. The hog, the solidungula, and the ruminantia rest only on the last phalanx of two toes, while the rudiments of two other toes do not

reach the ground; and in the horse there is only one toe remaining, of which the last phalanx alone comes to the ground.

But the order of action of the four extremities varies very much in quadrupeds. The main impulse to locomotion is given by the posterior extremities. The anterior extremities serve principally for support; in some rare instances, where the hinder extremities are ill adapted for locomotion, the anterior extremities drag the body after them, as is the case in the sloth.

1. *Walking pace*.—There are here four different acts; the four feet are advanced in a determinate order: first one of the fore-feet, then the hind-foot of the opposite side; then the other fore-foot, and lastly the other hind-foot. The two diagonal limbs, therefore, follow each other, and in the next moment they become the supports of the body; while by the extension of the joints of the other hind-leg on which the body as yet rests, and which is situated most posteriorly, the trunk is impelled forwards. While the body is thus moving forwards upon the support of the fore-leg just before advanced, the other fore-leg, which is the diagonal of the hind-leg, which has given the impulse, is in its turn moved forwards, and the hind-leg just mentioned immediately follows it. The other hind-leg is now the hindmost, and the movements are repeated as before. These are the usual movements of walking both in mammalia and in reptiles.

2. *The amble*.—In the amble the body of the animal is propelled forwards, first on the two legs of one side, and then on those of the other; it staggers or rolls consequently from side to side. This kind of movement is seen sometimes in young and weak horses,—also in the giraffe.

3. *The trot*.—There are here only two successive acts; two extremities, the fore and hind legs of opposite sides, being in each put to the ground simultaneously. The trot is the ordinary mode of rapid locomotion in mammalia and in some reptiles,—for example, in the salamanders.

4. *The canter*.—There are here three successive acts. The whole body is raised and impelled forwards by the hind-legs. The fore-feet come to the ground, one after the other,—either the right-foot first and then the left, or the left first; the hinder part of the body is then raised from the ground by the extension of the joints of the hind-legs, which are immediately afterwards advanced. The longer the hind-legs of the animal are, the higher must the fore part of the body be raised when the whole trunk is propelled forwards by the action of the hind-legs, which otherwise would tend to throw the hind part of the body over the fore part. This raising of the fore part of the body is necessary, for example, in hares and mice. The movement of these animals resembles leaping. The rodentia, in moving over a plane surface, step forward

with their fore-feet, and then bring the hind-feet after them. This kind of movement is likewise observed in frogs.

5. *The gallop* differs from the canter in the fore-feet being both put to the ground at the same time.

It was remarked by Cuvier, that the flexion and extension of the joints of the extremities in mammalia are performed in vertical planes, nearly parallel to the line of the vertebral column; while in oviparous quadrupeds, as the lizards, the articulation of the humerus and ulna, and that of the femur and tibia, are more frequently directed very much outwards,—a circumstance which influences the position in which the foot is put to the ground; and hence it is, that the trace of such animals can be distinguished by the position of the foot from that of a mammiferous animal.

*Leaping.**—The peculiarity of the movement of leaping consists in the body being raised completely from the ground for a longer period than in the other movements of locomotion. When the spring or leap is carried to the utmost, it is effected by the sudden extension of three joints, the hip, knee, and ankle joints, previously flexed in opposite directions. The foot, before the leap, may be applied to the ground by the entire sole, or only by the toes; in the former case, the foot is gradually raised from the ground, from the heel towards the toes, during the movement; if the toes only touch the ground, and the ankle therefore be already in a state of extension, this joint is still more strongly extended. The body is always inclined forwards towards the thighs. When, in a leap made with sufficient force to raise the body to a considerable height from the ground, the three joints of the lower extremities are extended, if no resistance were opposed to it, the length of the body would merely be simultaneously increased at each extremity; but the resistance offered by the ground causes the impulse to be imparted to the centre of gravity of the body, which is thus propelled, in the manner of a projectile, in the mean direction of the joints which are thus extended. The direction which the body takes in leaping does not depend on the inclination of one portion of the extremities only; for instance, it is not necessary for springing in the perpendicular direction that the leg should be nearly perpendicular to the floor, as Treviranus and others have asserted. Whatever inclination the leg may have with reference to the floor, the leap can nevertheless be made either forwards or backwards. The conditions which essentially facilitate the spring backwards are more evident when this movement is made in the most simple manner. Thus, the leap backwards may be made quite independently of any action of the ankle-joint, if, while standing on the edge of the heels of the shoes, the knee previously bent be forcibly

* Tiedemann's Zeitschrift für Physiol. t. iv. pt. i. p. 87.

extended without any perceptible movement of the hip-joint. In this case the body receives an impulse in the direction of a line drawn between the heel and the hip-joint; and, inasmuch as this line passes behind a perpendicular line falling from the centre of gravity to the heels before the movement was made, the motion given to the body is obliquely upwards and backwards.

A spring may be made in the same direction when the whole sole of the foot rests on the ground, also without extending the ankle, merely by the extension of the knee-joint. So also, when we spring backwards while standing on our toes, the only difference in the case is, that the point of support is changed; the impulse is still given by the extension of the knee-joint. As soon, however, as the hip-joint is brought within the line of the centre of gravity, it becomes impossible to spring backwards.

It is possible also to leap forwards while standing upon the heels, when the raising of the sole of the foot from the ground can have nothing to do with the movement. We may observe, that in making the spring thus the knee maintains its flexed position nearly unaltered, but that the angle between the trunk and thigh is forcibly straightened, and that the whole trunk has a share in the action. The two branches of the arch which here straightens itself are, on the one hand, the entire extremity which is held stiff from the heel to the hip, and, on the other, the trunk of the body; the line of direction in which this arch strives to straighten itself lies in front of the line of the centre of gravity.

Again, while the knees are kept bent and stiff, we may jump forwards by merely extending the ankle, if the line, towards which the two branches of the arch of the straightening ankle-joint tend, lies in front of the perpendicular of the points of support. Lastly, all the joints being made to act, the leap may be made either forwards or backwards, according as the mean direction which the different joints give to the body is forwards or backwards, or the direction of the line which they tend to in straightening themselves is in front of or behind the line of the centre of gravity or point of support. A spring in the perpendicular direction can take place with any inclination of the different joints, whether the direction of one or of another be forwards or backwards, if the different impulses which they tend to give compensate each other, so that the mean direction may be upwards.

There are two different modes in which quadrupeds leap. In one, the body, being projected upwards and forwards by the hind-legs, is received upon the fore-legs, and the hind-legs are drawn after. In the second kind of leap, the fore-legs are not called into action to receive the weight of the body: this is the case in many quadrupeds with very long hind-legs, namely, in some rodentia, as the jerboas (the genera *Dipus* and *Pedetes*); in some insectivora, as *Macroscelides*; and in some

marsupialia, as the kangaroo; this movement is presented also by many birds, as the passerine family, and by frogs.

Climbing.—The mechanism of climbing is sufficiently well known. Some climbing animals, as those of the feline tribe, the squirrels, opossums, and Phalangistæ, take their attachment by means of claws; the climbing birds (scansores) by means of their toes, one or two of which are directed backwards; some few animals, as the opossums and Phalangistæ, have a prehensile tail, and a distinct opposable thumb on the hind-foot. Some animals are specially organised for prehension by the length and freedom of motion of their digits, as the apes, in which there is an opposable thumb on both hind and fore feet. The howling monkeys (*Mycetus*) and the tribe *Cebus* have in addition a prehensile tail. The monkeys destitute of thumbs, the *Ateles* of Geoffroy, are equally adapted for climbing by the length of their fingers and toes, and by their prehensile tail. Among the edentata, some anteaters and the sloths are fitted for climbing by their long claws, with which they can embrace objects; the climbing anteaters have also a long prehensile tail. Both the anteaters and sloths walk with difficulty on the surface of the ground on account of the length of their claws; they both tread principally on the outer border of their feet. The arm and fore-arm are so disproportionately long in the sloths that they are obliged in walking to support themselves on their elbow-joints. It is, however, an error to suppose that Nature has neglected these animals, for their limbs are perfectly adapted for climbing and moving about on trees. The chameleon, amongst reptiles, may be compared to the sloth amongst mammalia; the toes of the chameleon, like the toes of climbing birds, are arranged in an anterior and posterior pair for facility of climbing; they have also a tail which they can wind round branches of trees.

The more minute details of the modifications which the extremities of vertebrate animals present in accordance with their destined use in flight, swimming, prehension, climbing, and burrowing, is the province of comparative anatomy. How different are the hand of the ray and that of the horse! in the former the fingers and their phalanges which compose the fin, are in extraordinary number, while the arm and fore-arm are wanting; in the fish-like mammalia, the cetacea, we again find an excessive number of phalanges, but a short arm and fore-arm are present; the solidungula, as the horse, present the other extreme,—the hand and foot are reduced to a single finger and toe.*

The movements of the articulata, particularly those of locomotion, in the last place demand our attention for a moment. While many insects (as the *Hydrophilus*, &c.) employ feet organised for

* On the adaptation of the hand to its uses in the different orders of animals, consult Sir C. Bell's *Bridge-water Treatise on the Hand*. London, 1834.

walking on solid bodies as oars, and others (the *Dytiscus*, *Notonecta*, &c.) move in the same way in the water by means of ciliated oar-like extremities; the Hydrometer, on the contrary, presents to our observation the remarkable phenomenon of a light animal body springing from spot to spot on the surface of the water, its feet supporting it on that fluid. The progression of insects on land appears agile and regular to a degree that we should not at first expect from seeing the great number of their feet. The movements are rendered easy by the numerous limbs engaged in them moving in a determinate order; thus the movement of progression in insects, though they have six legs, is quite simple. In watching insects which moved slowly, I perceived distinctly that three of their legs were always moved at a time; they were advanced and put to the ground, while the other three propelled forwards the body of the insect. The feet which moved simultaneously were the fore and hindermost foot of one side, and the middle foot of the opposite side; then the fore and hind foot of this side, and the middle one of the other side; so that in two steps all the six feet were set in action. In spiders, which have eight feet, four seem to be put to the ground while the four others are raised; the movements are here more difficult to observe than in insects; but it appears as if between two feet, which transmit the weight of the body to the ground, there is always one which is being raised. Indeed, even in the *Scolopendra* with fourteen feet, there seems to be a very regular order observed in the action of the feet, a certain number of which move simultaneously, while the appearance produced by the movement of all is that of an undulating motion.

In many light animals, and particularly insects, the feet are furnished with organs which enable them to attach themselves to perpendicular surfaces, even when such surfaces are quite smooth, or to the ceiling itself.* Thus flies have the soles of their feet furnished with organs which probably can be retracted in the centre, and leave an exhausted cavity, so as to act as suckers; and many similar apparatus exist in other insects, by which either close contact and adhesion are obtained, or really attachment by sucking. We have a similar example among reptiles in the *Gecko*, which has the under surface of the toes both of the fore and hind feet furnished with regular transverse plicæ, (like the sucker on the head of the *Echeneis remora*,) by the erection of which vacua are probably produced, and a firm attachment obtained. The *Gecko* is said to be able to run along perpendicular surfaces, and even on the ceiling.

This is the proper place to make mention also of a mechanism by which many animals are enabled to preserve with ease a position which appears to require great muscular effort. The standing posture of animals

* Sir E. Home, *Phil. Transact.* 1824; and *Lectures on Compar. Anat.* iv. 81.

generally, as well as of man, is maintained by a long-continued action of the extensor muscles ; but in some animals there is a mechanical provision facilitating the act of standing, which is in them continued without fatigue day and night. The storks and several other birds frequently stand for a long time without intermission upon one leg, and even sleep in that position. The peculiar structure of the ankle-joint in the stork which enables it to do this, was mentioned by Cuvier. In the middle of the anterior surface of the lower end of the tibia there is a fossa, into which a prominence of the metatarsal bone must be received before flexion of the joint can take place. In the extended state this prominence lies below the fossa, between the projections of the pulley of the tibia. The passage of the prominence into the hollow in question, so as to allow flexion, is opposed by the lower edge of the hollow which is prominent, and by ligaments which act like springs.* This mechanism, which enables the long-legged birds to stand with little muscular effort, is not, however, found in all cases in which animals are capable of standing for a long period on one leg. Ducks, for example, sleep standing upon one leg, though destitute of this mechanical provision ; a convincing proof that even in sleep that part of the nervous centres which is the source of all the movements of locomotion, can regulate the action of the extensor muscles for the maintenance of the equilibrium of the body.

In birds which sleep sitting, there is a provision for keeping firm the hold of the body on which they perch. It was first pointed out by Borelli, the correctness of whose explanation was questioned by Vicq d'Azyr, but has been admitted, and with good reason, by Cuvier. The tendons of the flexor muscles of the toes not only pass behind the tarsal joint, and therefore flex the toes when this joint is bent ; but they can be acted on by an accessory muscle which lies at the inner side of the thigh, and of which the tendon passes in front of the knee-joint. The flexion of both these joints under the weight of the body must, in consequence of this structure, flex the toes, and thus keep the attachment of the feet firm ; this effect may indeed be produced by flexing the knee and ankle joints after death.

A similar result is produced by the particular disposition of other muscles in the dog. Extension of the knee-joint in the dog makes the gastrocnemius tense, and consequently extends the heel. Hence a dog is still able, in some measure, to use the foot in walking, after the division of the ischiadic nerve, in consequence of the extensor muscles of the leg, which are not paralysed by division of that nerve, straightening the knee-joint, and acting on the heel, as we have described.

* Dr. Macartney, in the Transactions of the Royal Irish Academy, vol. xiii. p. 20.

SECTION III.

Of Voice and Speech.

CHAPTER I.

OF THE GENERAL CONDITIONS FOR THE PRODUCTION OF SOUND.

THE sounds of the voice and speech are not, it is true, the immediate result of muscular action, but of the vibrations of a peculiar apparatus which may be compared to a musical instrument: the tension of the instrument necessary for the production of sound, and the height and succession of the tones, are, however, determined by the contraction of muscles; hence the physiology of the voice and speech will be properly considered in this place. Before, however, entering on the consideration of the human voice itself, we must become acquainted with the general conditions on which the production of sound depends.

A sudden mechanical impulse upon the organ of hearing gives rise to the sensation of sound, which resembles a report if the impulse be violent, or is less intense if the impression be more feeble. The rapid escape of compressed air, or the rapid entrance of air into an imperfect vacuum, produces the sensation of sound, if the concussion of the air be communicated to the organ of hearing. But to produce sounds of uniform character which may be compared with each other, it is necessary that the impulse communicated to the ear should be of a particular kind, namely, a frequent repetition of the same impulse. The difference of sounds as to pitch or sharpness depends on the number of these impulses which occur during a certain time. The cause of the sensation of sound, in most cases, is the communication of the vibrations of sonorous bodies to the interior of the organ of hearing and the auditory nerve. The facts, that sonorous bodies have elasticity either from their attraction of cohesion, as the solid sonorous bodies,—or from their tendency to expansion, as the gases,—or from tension, as the sonorous cords,—and that all these bodies vibrate while in the act of emitting sound, naturally lead to the supposition that the vibrations alone are the essential cause of the sound. It would, however, be very incorrect to imagine that the *oscillating motion or vibration* imparted to the auditory nerve is essential for the production of the sensation of sound. On the contrary, it appears that the immediate cause of the sensation of sound, even when this is excited by the vibrations of sonorous bodies, is really the regular succession of *impulses* which the auditory nerve receives. This is proved by the investigation of those sounds which are produced, not by the

vibrations of an elastic body, but by a series of mere impulses quickly succeeding each other. If a piece of wood be held against the teeth of a rapidly revolving wheel, every stroke of the teeth of the wheel will be communicated as an impulse to the ear, and produce the sensation of sound. If, however, the wheel be now made to revolve more rapidly, so that the separate strokes on the wheel cannot be distinguished, in place of a succession of shocks, a continuous sound will be perceived; the pitch of which will be higher as the rapidity of the wheel's motion is increased. Still greater interest, in reference to the theory of the essential cause of sound being a quick succession of impulses, attaches to the tones which may be produced by a current of a gas, or liquid, such as water or quicksilver, interrupted at regular and very short intervals, particularly since liquids are not elastic, and therefore not capable of producing sound by vibration. Thus, in the siren, an instrument invented by M. Cagniard la Tour, a rapidly revolving wheel interrupts momentarily, and at successive intervals of very short duration, the escape of a fluid from the opening in the body of the instrument. Even when the revolving wheel is under water, and interrupts at regular and frequent intervals the current of water supplied by pressure from below, the impulses produced by the periodic escape of the fluid, if they follow each other in sufficiently rapid succession, give rise to a clear sound, of which the pitch is higher in proportion to the rapidity of the succession of the impulses, or moments of interruption of the current.

With reference to the human organ of voice, it is important to examine further the action of those sonorous bodies which produce the necessary number of impulses by vibration. Elastic bodies only are capable of producing sound in this manner. An impulse given to any part of such bodies is communicated to the whole mass, which is thrown into a state of vibration; the impulses produced by the vibrations are imparted to surrounding bodies, and in this way are transmitted to the ear.

The height or sharpness of the tones produced increases with the frequency of the vibrations. For the deepest tone ordinarily employed in music, the C of the open organ pipe, 32 feet in length, 32 vibrations of the air in the pipe take place in a second; for the octave higher than this there are 64 vibrations; for the next octave 128; and for the next there are 256 vibrations in a second. It being a matter of indifference whether impulses are produced by the teeth of a revolving wheel or by the vibrations of a sonorous body, we have now in an instrument invented by M. Savart, in which the sounds are produced by the successive strokes of the teeth of a wheel, an easy means of ascertaining with precision the number of vibrations necessary for the production of each tone.

The vibrations of a sonorous body may extend throughout its whole mass; or separate segments of the body may vibrate in opposite directions, these vibrating segments being separated by points (nodes or nodal points) which remain motionless. Small fragments of paper laid upon the nodal points are not moved.

The direction in which bodies vibrate is also various; it may be transverse, longitudinal, or rotatory. A cord stretched between two points, and vibrating from side to side, and a bar of metal fixed at one extremity, present good examples of transverse vibrations. Longitudinal vibrations occur in the air, in cords, or in bars of metal; they are excited in the last two kinds of sonorous bodies by friction in the longitudinal direction. In longitudinal vibrations a state of alternate compression and expansion is transmitted from one particle to another to the extremity of the body, or to a nodal point, and then takes the opposite direction. Chladni has observed the rotatory vibrations only in bars. The bodies which produce sound by vibrations are either gaseous bodies, such as the air, or bodies made elastic by tension, such as stretched cords or strings, or solid bodies elastic in themselves, as metallic bars, and metallic or glass plates. The laws which regulate the production of sonorous vibrations in these different classes of soniferous bodies are of great importance in relation to the theory of the human voice. We will take a cursory view of them, that we may perceive to which class the organ for the production of sound in man belongs.*

1. *Solid elastic bodies.*

Some of these bodies, as the strings of stringed instruments and the parchment of a drum, are rendered elastic by tension; in others, as metallic bars and plates, elasticity is a property of their substance. Either of these kinds of elastic bodies may influence the sound by their length and thickness only, when they have the shape of cords; or by their expansion in several directions, when they have an extended membrane-like form.†

a. Bodies elastic from tension.

Vibrating strings.—The frequency of the vibrations of stretched cords or strings increases proportionally to the shortness of the arc of vibration, just as a pendulum vibrates more frequently the shorter it is;

* In our account of the different means of producing sounds, we shall follow principally Chladni, Biot, Savart, and W. Weber. With respect to those kinds of instruments which have the nearest affinity to the human organ of voice, we shall adduce original observations of our own.

† Chladni, *Akustik*, Leipz. 1802, p. 64.

and the height of the tone is proportionate to the number of the vibrations.

A tense string gives out its deepest tone or fundamental note when it vibrates in its entire length: if, while its tension remains the same, it be divided into two equal parts by a bridge passed beneath it, the sound emitted by either half when made to vibrate, will be the octave of the lowest note, the vibrations of the string becoming twice as frequent. If one fourth of the string be isolated and struck, its degree of tension remaining the same, the sound produced will be the second octave, which is the result of vibrations four times as frequent as those of the fundamental note. It is a general law that in strings of the same substance, thickness, and degree of tension, the number of the vibrations is in the inverse ratio of the length of the string. When the length of strings is equal, but their degree of tension different, the relative frequency of the vibrations is in the proportion of the square-roots of the forces exerted in rendering them tense.*

The number of vibrations for the different notes intervening between the lowest or fundamental note of the string and the first octave will be in the inverse ratio of the different fractional lengths of the string corresponding to the notes. Thus the number of vibrations for the fundamental note being taken as 1, and the number for the octave, in which the length of the string is one half, as 2, the number of vibrations corresponding to the different notes in the scale of music universally adopted will be as follows :

	Fundl. tone.	Third.	Fifth.			Octave.		
Number of vibrations	1	$\frac{2}{3}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Names of notes	C	D	E	F	G	A	B	C

While a cord or string is giving out the sound corresponding to the vibrations of its whole length, it may also make more rapid vibrations in aliquot parts of its length, giving rise to other tones. If we strike a single isolated string or a monochord where there are no other chords which can be thrown into vibration at the same time, we shall perceive by a little attention other sounds mingling with the lowest or fundamental note of the string, and particularly those which stand in a simple numerical relation to the fundamental note with respect to the number of vibrations of each,—for example, the fifth note of the octave, and the third of the second octave [of which the number of vibrations are three and five, those of the fundamental note being one].

If a stretched cord be slightly touched at one-third, one-fourth, or one-fifth of its length, a nodal point is formed at the place of contact; and if the bow of the violin be then carried across the string, nodal

* Biot, *Precis élément de physique expérimentale*, t. i. p. 361.—*Lehrbuch d. Experimental-physik*, übers. v. Fechner, b. ii. p. 30.

points are developed between the other thirds, fourths, or fifths of its length, and, instead of the lowest or fundamental note of the string, sounds corresponding to the different lengths separated by these nodal points are given out; such sounds are called harmonic notes.

It being possible to obtain low notes from cords by diminishing their tension, when their length is otherwise not such as to vibrate sufficiently slowly for the production of such notes, we ought theoretically to be able to produce all the notes, high or low, on very short cords by mere variation of their tension. However, when the tension is much reduced, the vibrations become too irregular, on account of the diminished elasticity, to allow us to obtain a very deep tone from a very short cord by greatly lessening its tension. Nevertheless, very short cords, if they retain some elasticity when relaxed, as is the case with cords of caoutchouc, are still capable of yielding deep notes; and elastic laminæ, made tense in one direction, will, though very short, yield tones of great clearness if they form the boundary of a narrow cleft through which air is pressed, this current of air keeping the laminæ in a state of vibration. To this subject we shall return in speaking of the “tongued” or “reed” instruments.

Bodies of membranous form made elastic by tension.—In membranes stretched in one direction only, the tones yielded vary in accordance with the laws of cords or strings. When the extension is made in all directions, as in the drum, the height of the tones increases in the mean, as the tension is greater; but the laws which regulate the number of the vibrations in these kinds of sonorous bodies are not known, and a perfect knowledge of them would be of no importance in relation to the theory of the human voice.

b. Bodies elastic by the property of their substance.

Straight or bent rods.—The vibrations of these bodies are similar to those of strings or cords; their elasticity supplies what the tension of the cords effected; hence they vibrate as well when one end only, as when two are fixed. Metal bars or plates of this kind sound when struck; if the plates, whether of metal or wood, be sufficiently thin, they may be thrown into vibration by a current of air, as in the tongued or reed instruments, in which air is forced between a vibratory plate and the frame in which it is fixed. The mouth-harmonicon is an example of a simple-tongued instrument of this kind.

The pitch of the tones or the frequency of the vibrations in the elastic rods or bars is regulated by a different law from that which governs the vibrations of strings. The height of the tones, or number of vibrations within a given period, is here in direct ratio with the

thickness of the bar, and in an inverse ratio with the square of its length.

Inflexible elastic bodies of membranous form, bent or plane. Disks and bells.—The organ of voice has no similarity to either the rod-like or the expanded membrane-like forms of these solid elastic bodies. It is unnecessary, therefore, to dwell upon them.

2. *Elastic fluids. The air.*

The vibrations of the air, which produce sound, consist of successive condensations and expansions, which are propagated in wind instruments of the flute kind in a longitudinal direction through the tube. In most wind instruments the contained air is the seat of the sonorous vibrations, which pass as waves, backwards and forwards, from one end of the column of air to the other. The rapidity of the undulations is generally the same, whatever the width of the tube; and depends, principally at least, on the length of the wave or of the space which it traverses. Organ-builders, however, have learnt by experience that, to produce the same note, pipes must be made somewhat shorter if their diameter be increased; and M. Savart has discovered that a column of air yields tones of much lower pitch in flexible elastic tubes than in solid pipes of the same length. The relaxation of the walls of a flexible tube by impregnation with the vapour of water may have the effect of lowering the pitch of its fundamental note as much as two octaves.

Flutes or mouth-pipes.—The sounds produced by these instruments result from a column of air contained within a tube being thrown into vibrations by blowing upon it at some one point. This method of producing sounds is exemplified in the most simple manner by blowing over the mouth of a tube,—for instance, the bore of a key. The vibrations are excited in the same manner in the German flute, except that in it the column of air is acted on, not from its extremity, but from its side. In the common English flute and flageolet the air blown through the mouth-piece, and escaping by a side aperture, sets the column of air contained in the tube of the instrument in vibratory motion; and one class of the organ-pipes, the flute-, or mouth-pipes, have a similar construction. It is the air only which sounds in these instruments. Pipes of the same length, whether they be made of wood, metal, or pasteboard, yield notes of the same pitch, though of different “timbre.” The vibrations of the column of air necessary for the production of sound continue so long only as the current of air which excites them is maintained. Since there is no current of air through the tube itself in these instruments, but merely a vibratory motion of the column of air contained in it, the extremity of the tube may be either closed or open.

The simplest mode of vibration of the air in pipes with closed extremity is that in which the undulations pass through the whole

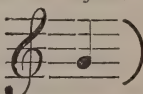
length of the tube without any nodal points arising in the column of air. The only nodal point is here the closed extremity of the pipe. A tube of the same length, but open at its extremity, yields a fundamental note one octave higher, a nodal point being formed in the middle of the column of air.* The pitch of the tones given out by a closed or open pipe becomes, *cæteris paribus*, lower in a direct ratio with the increased length of the tube; but the same column of air yields higher notes when the force of the impulse is increased, nodal points being developed by blowing strongly. The notes which MM. Biot and Hamel produced by blowing into a tube closed at one extremity stood with relation to each other, in regard to the number of vibrations producing them, in the same ratio as the series of uneven numbers. They were :

Names of notes . .	C, G ¹ , E ² , A ^{♯2} +, D ³ , F ^{♯3} -, A ^{b3} +, B ³ .
Relative number of sonorous vibrations in each . . .	1, 3, 5, 7, 9, 11, 13, 15.

(The fundamental note C being )

The series of notes which were elicited from an open tube, on the contrary, by the same procedure of blowing more strongly so as to increase the number of nodal points, corresponded to the natural series of numbers, namely :

Names of notes . . .	G, G ¹ , D ¹ , G ² , B ² , D ² , F ² , G ³ , C ³ , D ³ .
Relative number of sonorous vibrations in them . . .	1, 2, 3, 4, 5, 6, 7 $\frac{1}{2}$, 8, 10 $\frac{2}{3}$, 12.

(The fundamental note G being the fiddle G )

It was only by blowing feebly that they could obtain the fundamental note (G of the treble clef) from a glass tube one inch in diameter and thirty-seven inches long. The notes produced by blowing with different degrees of force into the end of an open tube, are, as the above series shows, more distant from each other the nearer they are to the fundamental note; and the higher the pitch of the notes, the nearer do the notes approach each other in the musical scale. Thus, between the fundamental note G and the first octave, for which the vibrations are twice as frequent, there is no intervening note; between the first octave and the second octave, G², for which the vibrations are four times as frequent, there is one note, D¹; between the second and the third

* On the theory of the open and stopped pipes of organs, consult Biot, loc. cit. t. i. p. 407. Fechner's translation, B. ii. p. 100.

octave, G^3 , for which the vibrations are eight times as frequent, three notes.

These laws are generally applicable, not merely with regard to the vibrations of atmospheric air, but also for all gases. It must be remarked, however, that the fundamental note varies according to the specific gravity and density of the gas, for organ-builders have found that the fundamental note of a pipe is a little altered even by holding it long in the hands. According to theoretical calculation, the tones of tubes of equal length should be in the inverse ratio of the square roots of the density of the gases, pressure and temperature being equal. The observed results do not exactly correspond with this theory.*

The embouchure of the tube has also some influence on the pitch of the fundamental note. This has been demonstrated by MM. Biot and Hamel. They employed a quadrangular pipe four feet long and four inches in diameter, the mouth of which, when open, was of the full size of the tube, but could be diminished by a sliding plate. The sounds produced according to the different size of the embouchure were as follows :

Size of the embouchure . .	66·0, 36·5, 26·0, 20·5, 16·5, 14·0,
Sounds	C, G^1 , E^2 , B^2 , D^3 , F^3 ,
Proportional numbers of } vibrations . . . }	1, 3, 5, 7, 9, 11.

The size of the opening indicated by 66·0 parts was one square inch. The proportional number of the vibrations for the different notes of the series thus produced was the same as in the series of notes produced by blowing with varied force into a tube closed at one extremity ; the effect of diminishing the aperture is therefore the same in a tube closed at one extremity, as that of varying the force of blowing. In neither case can octaves be obtained.

The influence of the embouchure upon the pitch of the pipe appears to me not to be at present satisfactorily explained. There is a mode of covering the mouth of the tube by which the pitch of the pipe can be considerably lowered. I find that by laying a card firmly upon the upper lip of a cylindrical mouth-pipe of brass, so as to cover a part of the orifice, I can lower the fundamental note more than a tone ; but if I place the card pressed against the upper lip of the tube over the opening in such a way that it covers the orifice like the roof of a house (dachförmig), the pitch of the pipe becomes still lower, and the more so the closer the roof-like card is depressed towards the opening. In this manner any notes, to the extent of some entire tones below the proper fundamental note of the tube, may be produced at

* Biot, loc. cit. p. 423. Fechner's transl. p. 107.

will; and by no means the notes corresponding to the numbers 1, 3, 5, 7. After forcing the plug or "tompion" (Stempel) of the pipe so far in as to reduce the length of the tube to two inches, I was able, by covering the embouchure in the roof-like manner already mentioned, to lower the fundamental tone from D to the G $\sharp$ below it, that is, nearly the interval of a fifth; and the intervening tones were easily produced by varying the degree in which the card was depressed over the opening. In a square pipe, one foot in length, also, the pitch could be lowered by this procedure of covering the mouth of the tube with a card inclined like a roof over the opening.

The preceding remarks refer to pipes in which the tube is destitute of side apertures; they are also applicable to the proper flutes, which are open tubes capable of yielding, when all the lateral apertures are closed, the different tones corresponding in the number of their vibrations with the series of numbers 1, 2, 3, 4, and 5, according as they are blown more or less strongly. By the successive opening of the side apertures the intervening tones can also be produced. The opening of each hole causes a sharpening of the fundamental note, and the degree in which the note is made sharper depends on the size of the hole left open, and its distance from the upper part of the instrument.*

We have lastly to inquire whether, by the use of the different means calculated to lower the fundamental tone of a pipe of given length, a very short tube can be made to yield low notes on submitting the column of air to a very feeble blast. A tube partially closed approaches the condition of one entirely shut at one extremity, in which the fundamental tone is a whole octave lower than that of an open tube of the same length; and the tone may be lowered nearly a fifth, as we have stated, by covering the embouchure with a card placed in an inclined position like a roof. Feebleness of the blast is not capable of lowering the tone below the fundamental note; there may, however, be means of enabling us to produce still slower vibrations, of sufficient regularity to constitute musical tones, by the application of a still weaker blast. A kind of pipe or whistle much in use among hunters, which is blown while held between the lips, and serves to imitate the different notes of birds, appears to possess this desideratum: although the conditions in it are very different from those which produce a lower pitch of the tones in the common pipes. This whistle, or bird-call, is made of ivory or brass, and is broader than it is long; measuring four lines in length, and from eight to nine lines in breadth. Each end is covered with a thin plate perforated in the middle by a hole, through which the air passes, so

* Further information respecting the mode of action of the flute and other pipes without reeds, must be sought in Biot's *Precis element. de Physique experimentale*. p. 402 to p. 429. *Lehrb. d. Experimental-physik*, p. 87—112, and in Muncke's article "Schall," in *Gehler's Physik. Wörterbuch*, 8 bd. p. 349—369.

that the current of air traverses the axis of the instrument. The principle of this kind of pipe has been investigated by M. Savart.* He supposes that the current of air, passing through both openings, carries with it a small portion of the air contained in the cavity of the pipe; and, thus diminishing its density, renders it incapable of resisting the pressure of the atmospheric air without, which consequently repels it and compresses it until a new rarefaction ensues; a repetition of this action he imagines to be the cause of the sound. By varying the force of the blast the tones of this instrument may be varied to the extent of half an octave or two octaves: and, by practice in regulating the current of air, the tones may be carried to a much greater extent, both higher and lower. The size of the instrument may be double or quadruple the size of that above indicated, or it may be less, without the results being in any remarkable degree altered. The deeper tones are more easily obtained when the instrument is large, and its parietes thin; but every instrument has a note which is produced more readily than others. The direction of the margins of the opening has an influence on the pitch; when they are directed obliquely inwards towards the cavity of the instrument, its tones are generally lower. The tones have also a lower pitch when the size of the openings is more considerable. We have at present no calculated theory of the vibrations of this instrument; it is not yet determined whether the air be really the seat of the primary sonorous vibrations, or whether this pipe should not rather be referred to the class of reed or tongued instruments, which we have next to consider. In the common reeds the mode of action of the tongue depends on its length and thickness only; but if one of the perforated plates in this pipe or whistle act as a vibrating tongue, the breadth as well as the length and thickness would have to be taken into account. However this may be, the instrument in question can be combined with a tube just as the common reeds can, and the sounds then produced resemble those obtained by the combination of a common "reed" with a tube. The fundamental tone, namely, is not that of the vibrating tongue, but one of the notes of the tube which is very near the fundamental note of the tongue. The notes of the "hunter's whistle," or "bird-call," combined with a tube of any dimensions, correspond like those of an open pipe in the number of their vibrations to the series of numbers, 1, 2, 3, 4, 5, &c.

3. *Musical instruments in which the properties both of solid and of fluid elastic bodies come into play. Reed, or tongued instruments.*

These are musical instruments consisting merely of a simple vibrating tongue, which is set in motion by means of a current of compressed air such are the jew's-harp and mouth-harmonicon. Experience has shown

* Magendie's *Journal de Physiol.* t. v. p. 367.

that such vibrating tongues may be formed not merely of bodies elastic by virtue of their property of cohesive attraction, as metal and wood, but also of laminæ or membranes made elastic by tension. From the combination of vibrating tongues of either kind with a tube or pipe, compound instruments result; constituting, when the tongue is formed of solid elastic substances, what are known by the name of "reed-instruments." The theory of the action of these instruments is of the greatest importance in connection with the inquiry into the mode of production of the human voice.

First class of tongued instruments.

a. Tongues without superadded tube.

The simplest-tongued instrument of this kind is the jew's-harp, which consists of a lamina of steel lying between two parallel bars of steel, and fixed at one end. The ordinary mode of producing the sonorous vibrations in this instrument, is by striking the thin lamina with the finger while the bars are held between the teeth; but the tongue may be thrown into vibrations by merely drawing a current of air into the mouth. The mouth-harmonicon consists of several tongues fixed in one frame. Into the oblong rectangular openings in a small metal plate are fitted thin laminæ of metal, which are fixed by one extremity, but can vibrate in their frame without coming in contact with it. These laminæ are thrown into sonorous vibrations by holding the common frame between the lips and forcing air against the tongues.

The mouth-pieces or reeds of reed-instruments, and of one class of organ-pipes, have the same mechanism. A half-cylindrical tube of steel or brass, open at one end, has its flat side towards the other end, which is closed, formed by an elastic plate which does not completely close the tube at this part, being able to vibrate within its cavity; air forced into the open end of the tube passes out at the sides of the elastic lamina and causes it to vibrate. The tongue can also be made to vibrate by forcing air upon it from the outside; the end of the tube at which the tongue is situated being held free in the mouth, a blast of the breath passes into the tube at the side of the tongue, and throws it into vibrations; and it is thus that the air acts on the reeds in organ-pipes. It is evident, therefore, that the only essential part of the reed is the tongue itself and the frame, as in the jew's-harp.

The mode in which the vibrations of sonorous tongues are produced appears to me not to have been hitherto satisfactorily explained; Fechner has expressed the same opinion. I believe the true theory to be this:—The tongue is forced by the blast of air out of the opening in which it is fixed, receding from the impelling force with gradually diminishing velocity in accordance with the law of inertia, until its elasticity, which increases in power in proportion as the tongue is bent,

counteracts the force of its motion. The current of air still continuing, the tongue would remain in the position thus given it, were it not that, when removed from the opening, it is much less exposed to the pressure of the air, and therefore is carried back by its elasticity like a pendulum, and would indeed return to its straight position with increasing velocity, did not the continued current of air in some measure retard it. When thus restored by its elasticity to its former place in the opening of the frame, the tongue is again forced out by the air, which now acts with greater power upon it. If the pressure of the air upon it were constantly the same, the tongue would be kept continually in one position, that, namely, in which its resistance balances the force exerted upon it.

Not merely a confined current of air will throw a tongue into sonorous vibration; even a current of air blown free upon the surface of a thin tongue, such as those of the mouth-harmonicon, will, if sufficiently strong, set the tongue in motion. A very thin tongue, and the longest in the harmonicon, may, even when removed from its frame, if fixed at one end, be made to emit a feeble sound by blowing a strong current of air upon it from a tube with a small orifice. The current of air must, in this case, be directed upon the edge of the tongue, and perpendicularly to its surface. The theory of the vibrations thus produced seems to be the same as that just given for those of the tongue set in motion by a confined current of air. The fact that a sound can be obtained from a tongue free from all surrounding framework, shows clearly that too much importance should not be attributed to the ordinary mode of forming the reeds and tongued instruments, and to the passage of the air between the tongue and its frame.

The law regulating the variations in the notes yielded by the tongue of a "mouth-piece" or "reed," has been shown by M. W. Weber* to be the same when the tongue is thrown into vibrations by a current of air,—as when the vibrations are produced by striking or bending the tongue. It is the same law which regulates the vibrations of vibrating rods; namely, that the frequency of the vibrations of two rods of equal thickness and same material is in the inverse ratio of the squares of their length. The same experimenter has found that the note given out by a reed without a tube is the same as to pitch, whether it be produced by a current of air or by striking the tongue. The pitch or sharpness of the note is, for the most part, independent of the strength

* The nature of the sounds produced by reeds has been investigated by W. Weber, *Leges oscillationis oriundæ si duo corpora diversa celeritate oscillantia*, &c.—Abstracts of his researches are given by Chladni in Kastner's *Archiv*. t. x. p. 443; by Muncke in the art. "Schall," Gehler's *Physik. Wörterb.*; and by Fechner in his translation of Biot's *Experimental-physik*. bd. ii. p. 112. Compare Weber in Poggendorf's *Annal*. t. xvii. p. 193.

of the blast;* but the strength of the tones can be increased by blowing with increased force. It was shown by M. Biot that the chemical properties of the gas used for exciting the sonorous vibrations of elastic tongues have no influence on the pitch of the tone. The dimensions of the fissure left between the tongue and the frame within which it vibrates, are also, according to M. W. Weber, of little importance. A large size of the opening increases the difficulty of eliciting the tone, but does not alter its pitch.

Theory of the production of sounds by vibrating tongues.—The vibrations of tongues obey, it appears, exactly the same laws as the sonorous vibrations of metallic rods; but it is generally supposed that there is this difference, that in the latter case the sound is produced really by the vibrations of the rods, while in the case of tongues and reeds, the air itself is the source of the sound. The same difference is supposed by many to subsist between the sounds produced by striking a tongue, and that obtained when the tongue is thrown into vibration by a current of air. In the first case, the tongue alone is the source of the sound: in the second, the tongue will also necessarily produce a sound; but the air itself is supposed to be the main source of the peculiar tones. The grounds of this view are the following:

The sound produced by a tongue thrown into vibration by striking it is feeble; that emitted when a current of air is forced upon the tongue is strong; the timbre of the two sounds is also quite different. Hence it is concluded that, although a difference of size of the cleft at the side of the tongue does not modify the sound, the air must nevertheless have an essential share in the production of the sound; the air receiving, under the conditions in which tongues vibrate, a regular succession of impulses, though nodal points are not developed. We know that, for the production of a sound, it is only necessary that a certain number of impulses should be propagated to the auditory nerve, and we know that vibrations produce sound merely by giving rise to these impulses. The manner in which the tongue vibrates in its frame is supposed to give rise to the production of impulses of the air, and consequently of sound, in the same way as the action of the instrument called the siren; namely, by each vibration of the tongue interrupting for a moment the current of air through the opening. The pitch of the note would, as in the siren, depend on the frequency of the interruptions to the current of air; and, as according to this theory the interruptions to the current of air are produced by the vibrations, the frequency of the interruptions will be equal to that of the vibrations. This theory of the

* This is the more remarkable, since we shall find that notes obtained from membranous tongues may be raised several semi-tones by increasing the force of the blast.

sounds produced by vibrating tongues must be by no means regarded as proved. Even the sounds which can be produced by directing a strong current of air from a small tube against a thin and sufficiently long tongue of a mouth-harmonicon merely fixed at one extremity, and not surrounded by any frame, are alone sufficient to prove that the sounds produced by vibrating tongues do not depend solely on the impulses of the air; although in such an experiment the current of air must be somewhat arrested by the return of the vibrating tongue, while it would have a free course at the moment of the vibration, in which the tongue is carried out of the line of the current. We shall consider this subject more fully hereafter [in Appendix to the section on the voice].

b. Vibrating tongues, or reeds, combined with a tube which modifies their pitch.

The sound yielded by a reed or tongue is much altered in pitch when a tube or pipe is superadded to it,—as in the oboe, clarinet, and bassoon. Here the air which sets the tongue in vibration has to traverse the whole length of the tube before escaping into the atmosphere; and the instrument is a compound of two, of which the sonorous vibrations are regulated by different laws. The pitch of the reed and that of the tube, sounded separately, may be quite different; but combined they react on each other, or accommodate themselves to each other in such a way that only one note is heard, which is neither always the fundamental note of the reed alone, nor that of the column of the air in the tube sounded without the reed. Hence not only does the frequency of the vibrations of the reed and column of air become the same, but they must reciprocally accommodate themselves to each other.

We owe the knowledge of a trustworthy theory of the action of these compound reed-instruments entirely to the labours of M. W. Weber.* We cannot here give all the results which he has obtained; but those which form a basis for an inquiry into the action of reed-instruments with membranous tongues—the instruments which most resemble the organ of voice—must be detailed.

1. The pitch of a reed may be lowered, but cannot be raised, by joining to it a tube.

2. The sinking of the pitch of the reed thus produced is at the utmost not more than an octave.

3. The fundamental note of the reed thus lowered may be raised again to its original pitch by lengthening the tube; and, by increasing

* Poggendorf's Annal. xvi. and xvii.; and an account of his experiments by Fechner in his Repertorium der Experimental-physik, i. p. 314 to 334.

the length of the tube after this, the fundamental note can be again lowered, but only to a certain extent.

4. The length of tube necessary to lower the pitch of the instrument to any given point depends on the relation which exists between the frequency of the vibrations of the tongue of the reed and those of the column of air in the tube, each taken separately.

5. Thus: the fundamental note of the reed-instrument sinks gradually as the tube is lengthened, until the tube acquires such a length that it would separately yield the same fundamental note as the reed of the instrument without the tube; the pitch of the instrument then suddenly rises to the pitch of the reed. By increasing still further the length of the tube, the pitch of the instrument may be again lowered to the "fourth" of the descending scale; and when the length of the tube has reached the double of that which would give the same note as the fundamental note of the reed, the pitch of the instrument again rises to that note. By still increasing the length of the tube, the pitch may be again lowered to the minor third, after which it again rises to the original note. During the transition, two different notes can be produced by varying the force of the blast. (These facts are, as we shall presently see, capable of useful application in explaining the action of reed-instruments with membranous tongues.)

6. If the note yielded by the reed alone corresponds with any one of the series of harmonic tones of the tube, the pitch of the two united does not necessarily differ from that of the reed alone, if they be sounded by a gentle blast; but, by blowing more strongly, the octave below the original note, or the fourth, minor third, or other intervals of the descending scale corresponding to the numerical series $\frac{7}{8}$ $\frac{9}{10}$ $\frac{11}{12}$, may be produced.

These facts furnish certain data for determining whether the organ of voice, or other musical instruments, should be regarded as simple flute or mouth-pipes, or as reed-pipes; for if a wind instrument can by the addition of a tube be made to yield tones of any depth in proportion to the length of the tube, it must certainly be regarded as a flute-pipe, the column of air within being alone the cause of the sound: but if, on the contrary, the pitch of the instrument can be lowered only an octave or less, by lengthening the tube, the embouchure remaining the same, then we may be certain that it is a reed-instrument.

In the clarinet, oboe, and bassoon, the different notes are produced by closing or opening a series of holes, the proper position of which has been determined by experiment: in the reed-pipes of the organ, which are tubes with a reed inserted into them through a plug, each note has a separate pipe.

Disk-shaped or metallic tongues.—It has been shown by the experiments of Clement and Hachette, confirmed by M. Savart, that a thin plate

held before an opening in a plane surface, through which a current of air is forced, is thrown into vibrations, and gives rise to very deep dull sounds. And I have found that sonorous vibrations may be produced by forcing air between the edge of a circular disk of brass, fixed by a central rod, and the sharp border of a surrounding frame. We might, hence, expect that a circular disk would act as a vibrating tongue when air is forced through an opening in its centre; and, at first sight, the hunter's whistle, described by Savart, would seem to present us with an example of an instrument on that principle. But the opening in the centre of the disk in this "whistle" is proportionally much larger than the cleft between the tongue and its frame can be to allow of sound being produced; though it is true, that a very delicate metallic tongue can be made to vibrate by forcing a strong current of air against its edge even when there is no frame to confine the air. The whistle or bird-call has, however, more analogy with a pipe or flute in which the air only vibrates, than with a reed-instrument. I can produce sounds by drawing in air through the central opening of a disk of ivory so thick that its borders cannot vibrate, and therefore cannot act as a tongue.

Second class of tongued or reed instruments.

Instruments with membranous tongues rendered elastic by tension.

The tongues of this kind have hitherto been little studied, which is the more to be regretted, since a knowledge of their action would be a key to the theory of the organ of voice in men and birds. MM. Biot and Cagniard la Tour have sought to imitate the membranous tongues of the larynx,—namely, the vocal cords,—by stretching elastic bands of caoutchouc over the end of a tube. Henle also has formed an artificial larynx by means of animal membrane. Hitherto, however, the subject has not been sufficiently investigated to afford data for a perfect comparison between these artificial instruments and the organ of voice. I have therefore made the action of vibrating bands and membranes my study, and beg the reader's attention to the following results of my observations, a knowledge of which is necessary for the understanding of the experiments on the human voice and larynx to be afterwards detailed. The reader should also peruse the foregoing account of the principal facts regarding the action of musical instruments; otherwise what follows will not be intelligible.

The sonorous tongues which we have hitherto considered were solid plates of metal or wood, which vibrate according to the same laws as vibrating rods or bars. We saw that on account of being so short they give no sound, or only a very feeble one, when struck; but that the continued impulse of a current of air causes them to yield a sound which

corresponds in pitch to the elasticity and length of the tongue. Bodies made elastic by tension, also, if much shortened, do not emit sound when struck, but are capable of being thrown into sonorous vibrations by a continuous current of air; such are the membranous tongues, the properties of which we are about to examine. These tongues may be rendered tense by stretching in one direction only, like the musical strings; or they may be extended in all directions, like the parchment of the drum.

Here, again, we shall consider separately the simple tongues, and the tongues combined with a tube modifying their tone.

A. Simple membranous tongues without a tube.

a. Tongues extended like vibrating cords.

A strip of thin membranous caoutchouc, one or two lines in breadth, stretched over a ring of wood or a four-sided frame, gives, when struck as a musical cord, a feeble sound only, as harsh as that of a metallic tongue when struck. But if a plate of pasteboard or wood be fixed to the ring on either side of the strip of caoutchouc, and so near it as to leave merely a narrow cleft between, a musical instrument is formed, which, when blown in the same way as the mouth-harmonicon, yields a clear, strong, and musical note.

We showed that sound could be elicited by forcing air from a tube upon a metal tongue, even though it were not fixed in a frame. The same experiment succeeds much more easily with a narrow tongue of caoutchouc stretched over a frame of eight lines, or one inch in diameter. Such a tongue, when a current of air is directed perpendicularly upon it at one of its edges, vibrates from side to side, and emits a musical sound; or if the current of air be thrown from the side over one surface of the elastic band, which is the better method of making the experiment, it immediately vibrates upwards and downwards, and a clear, strong sound, of the same character as when the air is forced through a cleft on each side of the tongue between it and solid plates of card or wood, is heard. When the current of air from a small tube is directed transversely across the elastic band at its middle, or between its middle and one end, the fundamental note of the band may in either case be produced; but sometimes, if the current strikes the surface of the strip of caoutchouc further from the middle, and the blast be strong, a different note is the result. The force of the blast, however, influences in some measure the pitch of the note produced. By laying a spatula perpendicularly across a caoutchouc tongue tied across a ring, in such a way that the edge of the spatula touches the middle of the tongue and the ring at two points, and then directing a current of air against one half of the band of caoutchouc, the octave of its proper fundamental note is produced. By increasing the tension of the band of caoutchouc, sounds of higher pitch

can be obtained, and very high notes thus produced are still clear and full. On the other hand, the fundamental note of the band may be raised half a tone or more by increasing the force of the blast. The general law, however, regulating the vibrations of these membranous tongues, as of the common vibrating strings, is, that their number is in the inverse ratio of the length of the tongue, and probably also, as in the case of the strings, in the direct ratio of the square roots of the forces producing their tension. The tongues of metal and wood vibrate, we have seen, according to a different law, namely, in the inverse ratio of the squares of their length. The membranous tongues differ from the common vibrating strings merely in the circumstance of the pitch of their note varying with the mode in which the current of air acts upon them. The tongue being tied over the mouth of a tube, with a plate of pasteboard or wood on either side, the sound produced is half a tone or a whole tone lower, when air is drawn through the intervening clefts into the tube, than when it is forced out, though the force of the current be as much as possible the same in both directions. The force of the current of air influences the pitch of the note produced, as well when the air is drawn into the tube as when it is forced out. The size of the cleft at each side of the membranous tongue has no very perceptible influence on the pitch of the note, but the sound is more easily produced when the cleft is narrow. If any point of the tongue strike an inequality of the lateral bounding plates during its vibrations, a nodal point is developed, and a much higher note than the fundamental note of the tongue is heard.

The membranous tongues, made elastic by tension, may have either of three different forms, namely,—

1. That of a band, extended like a cord, and included between two firm plates, so that there is a cleft for the passage of air on each side of the tongue. This is the form which we have already considered.

2. The elastic membrane may be stretched over the half or any portion of the end of a short tube, the other part being occupied by a solid plate, between which and the elastic membrane a cleft merely is left.

3. Two elastic membranes may be extended across the mouth of a short tube, each covering a portion of the opening, and having a chink left open between them.

The laws of the action of the second form of tongue are exactly the same as those which we found to regulate the action of the first form. The only circumstances to be noticed are, that the note produced when the tongue was made to vibrate by blowing through the tube was from half a tone to a tone higher than when the sonorous vibrations were excited by forcing a small current of air upon the edge of the membrane itself. When the air was drawn into the tube through the cleft

between the tongue and solid plate, a higher note was produced, unless the solid plate was placed somewhat within the tube, and its border behind that of the membranous tongue, when the sound produced was lower in pitch than the fundamental note. The position of the solid plate is of importance. If, when the air is forced from within the tube outwards, the border of the plate be directly opposed to that of the membranous tongue, the note produced may be the interval from C to F higher than when the plate of pasteboard is placed somewhat more forward than the vibrating tongue.

The third form of tongue, that in which two elastic membranes alone form the borders of a cleft, as at the glottis, is the most interesting. The two membranes may have either the same or different degrees of tension. To ascertain that they have the same degree of tension it is only necessary to sound each separately, which may be done by directing a current of air from a fine tube upon the edge of one while the other is depressed, or covered with a thin lamina of pasteboard; their tension may then be altered, until they each yield separately the same note. The sound emitted by the two tongues conjointly, when both have the same tension, is of a deeper pitch than the fundamental note of each separately; in three experiments the difference was a semitone. If the two elastic tongues have different degrees of tension, so that the pitch of the sounds they yield separately is different, they frequently appear not to accommodate their vibrations to each other, as the metal tongue of the reeds and the column of air in the tube of reed-instruments do. It is seldom that the sounds of both tongues are heard when the tube to which they are fixed is blown. Usually we hear the note of one only, as if the tongue which is more tense or more lax than the other was not sounding, or as when one tongue is covered and fixed by a plate of pasteboard. Frequently the tongue, which on account of not being sufficiently tense yields sound with difficulty, vibrates but feebly, and is somewhat protruded by the current of air. Sometimes the vibrations of the two tongues seem really to influence each other reciprocally. That such may be the case, has been noticed by Cagniard la Tour: he observed, that if the relative tension of the two tongues was, for example, such that there was an interval of a "fifth" between the notes they gave separately, the note which the two emitted when sounded conjointly was the intervening "third." That this is sometimes the case I have no doubt, but I must point out a source of error in such experiments. Frequently the tongues appear to be accommodating their vibrations to each other when such is not really the case. Thus, in one of my experiments, the two tongues differed from each other in their pitch about an octave: the tongue of the highest pitch gave, when the other was covered with a solid plate, the note F; but, when both were sounded, the note heard was the B below this F.

Here, then, a membranous tongue giving the note F, and another tongue with the pitch of an octave lower, seemed to influence each other reciprocally so as to produce the intermediate note B. But this reciprocal influence or accommodation of the vibrations was not real; for on pressing back the tongue of the lower pitch, and putting in its place a solid plate of pasteboard, the edge of which was made to project somewhat in front of the edge of the opposite elastic tongue, this tongue did not give out the F as when the edge of the solid plate was on the same level with it, but the lower B. The position given to the pasteboard plate to cause the tongue to yield this note, was exactly that which the tongue of lower pitch had assumed when protruded by the blast of air, and vibrating feebly. The law regulating the action of two tongues of unequal tension fixed over the mouth of a tube, with a narrow cleft between them, is the following. When one tongue is most readily thrown into vibrations by the current of air, the sound is emitted by it alone; but, if the blast be such as to throw them both into motion, they may both vibrate together, and by reciprocation produce a simple sound intermediate between the fundamental notes of the two separately: they may also, however, emit two different sounds; or, the blast being modified, the two sounds may be produced in succession. The metallic tongues of the mouth-harmonicon do not accommodate their vibrations to each other when they are sounded together by forcing air into the instrument from one general reservoir, the mouth.

The elastic membranous tongues, fixed to the end of a tube, may be so placed that their edges overlay each other, and clear tones will still be produced.

The sound elicited from membranous tongues may be much modified by arresting the vibrations of the tongue at different points by the finger. By touching the outer part of one of the caoutchouc bands tied to the end of a tube, I cause the note produced to be somewhat sharper; and the nearer the pressure of my finger approaches the cleft through which the air passes, the sharper become the sounds.

The membranous tongues differ from the metallic with respect to the effect of increased force of the current of air on the pitch of the notes they produce. When vibrations of a soniferous body are longitudinal, as in a column of air, the fundamental note is somewhat raised by increasing the force of the blast; but in bodies which vibrate transversely, as strings and metallic tongues, an increase of the moving force, while it causes the sphere of the vibrations to be more extensive, lowers in some degree the note given out. Hence the tone of a reed with metallic tongue becomes somewhat deeper when it is blown strongly. The cause of this, perhaps, may be, that when the blast is more gentle, the base of the tongue is not made to vibrate. The membranous tongues differ from other bodies which vibrate transversely

in yielding constantly a higher note when thrown into action by a stronger blast of air. (It appears to me, however, that the tone of a mouth-harmonicon with a very delicate vibrating tongue also rises somewhat when the instrument is very strongly blown; and the very delicate vibrating tongue of a child's trumpet, whether the mouth-piece which contains the tongue be alone sounded, or the whole pipe, can by successive blasts of increasing strength be made to rise through the whole extent of an octave and a half without intervals.)

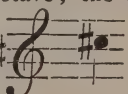
b. Tongues stretched in several directions, like the parchment of drums.

Hitherto we have considered merely the membranous tongues stretched in one direction only; but two membranes extended over the end of a tube, with a cleft between them, may be stretched in several directions, or one membrane may be stretched in all directions with merely a round opening in the middle for the passage of the air: both these cases would present some analogy to the parchment of the drum, but the tongues of the form last mentioned are generally insusceptible of sonorous vibrations, and in the rare cases where they do yield a sound, it is a very feeble one.

B. Membranous tongues combined with a tube.

The addition of a tube below the tongue influences the notes yielded by a membranous tongue in much the same way as, we have seen from M. Weber's researches, it does those of the metallic tongues.

The note does not become uniformly higher or lower in a direct ratio with the length of the tube; the experiments which I have performed by means of a reed furnished with a tongue of caoutchouc, and a tube capable of being lengthened by small degrees to the length of four feet, show that the effect of the addition of a tube on the note given out by the membranous tongue depends on the relation which the proper fundamental note of the tongue bears to the fundamental note of the tube. Usually the note becomes lower and lower by semitones, in proportion as the tube is lengthened, until the tube becomes nearly of the length proper to give the same fundamental note as the tongue; there is then a sudden rise to that note. But the lowering of the note ceases before the tube has reached such a length as to be in unison with the tongue, for the pitch is not easily lowered an entire octave; the extent

to which the note sinks is, for example, only from C#  to A 

from D#  to G#  or from E  to A 

When the note has risen to the pitch of the tongue, or to a note near the fundamental note of the tongue, the further increase of the length of the tube again lowers it, until the tube has attained about the double of the length which it had when the note rose before to the pitch of the tongue, to which pitch it then again rises. Further lengthening of the tube again lowers the note produced. In several instances I found that the pitch of the instrument continued to fall for a longer period, namely, till it was nearly as low as the lower octave; in such cases the rise to the fundamental note of the tongue did not occur when the tube was of about such a length that its fundamental note was that of the tongue, but not until the tube had double this length. The cause of this difference I could not determine. Experiments of this kind with membranous tongues do not admit of the same degree of precision as can be attained in experiments with metallic tongues,* on account of the proneness of the note yielded by membranous tongues to vary as much as a tone or semitone, according to the force of the blast of air, while the note given out by metallic tongues is very little affected by this cause. This source of inaccuracy might be avoided by using bellows compressed by a certain weight to give the blast; but there are advantages attending the blowing with the mouth in such a manner as to produce the slightest current of air which will excite sound,

* The following are the results given by W. Weber (in Poggendorf's *Annal.* xvi. 425. & xvii.) as afforded by his researches on the influence of a tube on the sounds yielded by reeds with metallic tongues:

(Let a designate one-fourth of the length of the tube, the column of air in which yields the same fundamental note as the metallic tongue without the tube; the length of tube designated by a will, of course, be longer or shorter in proportion as the fundamental note of the tongue is deeper or higher.)

1. A tube gradually lengthened, until it equals a , deepens the note in an imperceptible degree.

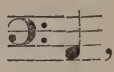
2. While the tube is gradually lengthened from a to $2a$, the deepening of the note becomes marked; but still increase of the length of the sonorous vibrations is not proportionate to the increase in length of the column of air.

3. While the tube is lengthened from $2a$ to $3a$, the pitch of the note falls rapidly, and nearly in the ratio of the increase in length of the column of air.

4. During the elongation of the tube from $3a$ to $4a$, the pitch of the fundamental note falls still more rapidly, quite as rapidly as the length of the tube increases, till at length it is an octave lower than the fundamental note of the tongue alone. Further lengthening of the tube causes the sound produced to rise suddenly to the pitch of the original fundamental note of the isolated metallic tongue. If the elongation of the tube be continued after this, the fundamental note falls in pitch in the same way as before; and, when the tube has reached the length of $8a$, is an interval of a "fourth" deeper than the proper fundamental note of the isolated tongue. Further lengthening of the tube causes the note to rise again suddenly to its original pitch, from which it again falls as the tube is lengthened, until, at the length of $12a$, the note produced is the "minor third" of the fundamental note of the tongue. It then rises again to this fundamental note. [See also page 985 supra.]

and any other mode of effecting the blast is scarcely admissible, since frequently a note cannot be obtained from the instrument except by a particular mode of blowing and position of the lips (without any alteration in the force of the blast). [The experiments from which the above results are deduced are given in the Appendix.] Besides the variation of the length of the tube, there are two means by which the note yielded by a membranous tongue combined with a tube may be altered; namely, change in the force of the blast, and partial occlusion of the end of the tube.

The note produced by blowing through a reed with membranous tongue furnished with a tube of some length,—for example, four feet,—can be raised in pitch almost an octave in successive semitones by altering the force and manner of blowing. Notes which cannot be produced by blowing with increased force can be obtained by making the opening of the lips narrower while the blast is given. The fundamental note of a membranous

tongue combined with a pipe four feet in length was C 

by increasing the force of the blast, and contracting the opening of the lips at the same time, or without this, I could produce the sound of C#, D, D#, and E, with ease; F with great difficulty; then again, F#, G, G#, A, and A#, readily; but B was difficult to produce, and was not a perfect tone.

It has been stated by the MM. Weber,* that reed-instruments with metallic tongues are capable of yielding harmonic tones, the octave or the fifth of their fundamental note, by the developement of nodal points, just as is the case with pipes without vibrating tongues, which are closed at one extremity. But it is peculiar to the instruments constructed with membranous tongues, that the note yielded by the tongue, whether this be combined or not with a tube, can be raised by semitones to a certain extent by gradually increasing the force of the blast. If in place of dry elastic tongues of caoutchouc, moist elastic membranes—for example, arterial tissue,—be used, the note can be raised by semitones nearly the extent of a “fifth,” when no tube is superadded.

The size and condition of the lower opening of the tube has an influence on the note emitted by the membranous tongue. The length of the tube being three inches, I could, by gradually covering a larger and larger portion of the lower opening, cause the note to sink the extent of a “fifth.” The tube being six inches in length, covering half the orifice caused a lowering of the note the extent of a semitone; the introduction of the finger lowered the pitch from C to the F below. In many instances, however, the introduction of the finger had directly the

* *Wellenlehre*, 526.

opposite effect, namely, the production of a higher note. The cause of this apparently contradictory result was for a time an enigma. At length, however, I found that as long as the note is sinking with the increasing length of the tube, covering its extremity lowers the note still more; but that, when the length of the tube has reached the point where the pitch of the instrument is about to rise again to the fundamental note of the tongue, covering the orifice of the tube may induce a higher note, and even cause the note to rise at once to the pitch of the tongue alone.

A considerable constriction or obstruction of the tube at the other extremity, namely, close to the tongue, generally causes the note to be higher.

If the ordinary reed of a clarionet be replaced by a reed with a tongue of caoutchouc, it is found that the influence of the side-holes of the tube of the clarionet on the notes elicited is much less than when the instrument is furnished with its ordinary reed. In a clarionet with the usual construction the successive opening of the side-holes and keys from below upwards raises the notes by successive semitones; but, when the clarionet has a membranous tongue, the rise of the notes thus produced is very slight, not being perceptible, except when the highest holes are opened, and at last amounting to no more than a tone.

C. Influence of a tube prefixed to vibrating membranous tongues upon the sound they produce.

The influence exerted by the prefixed tube or "porte-vent" upon the pitch of a reed-instrument with metallic tongue was, it appears, first observed by M. Grenié.* The nature of this influence has not been hitherto satisfactorily elucidated. I find that the length of the tube which conveys the current of air to a membranous tongue has as powerful an effect in lowering the pitch of the sound produced as that of the tube beyond the tongue. This is a point of very great importance in relation to the organ of voice, and must be here fully investigated.

There are five principal conditions in which a vibrating tongue may be sounded. 1. The tongue may be destitute of any bounding frame, and have no pipe or tube either above or below it; and it may be thrown into vibrations by a free current of air blown upon it from a small tube. 2. The tongue may be bounded by a frame without any tube, and the air may be forced upon it directly from the mouth, the frame being embraced by the lips. 3. The tongue may be sounded in the same manner as in the last case; but to the tongue and frame is

* See Muncke in Gehler's Physik. Wörterb. bd. viii. p. 376.

superadded a tube or pipe, through which the air passes after acting on the tongue. 4. The tongue has no tube beyond it, but the current of air before reaching it passes through a tube, to the lower end of which the tongue with its frame is fixed. 5. The tongue has both a tube prefixed, and one attached to it below.

The simplest form in which the influence of a tube prefixed to the membranous tongue upon the sound which it emits can be examined, is that where the tongue is stretched over the lower end of the tube which conducts the current of air, and has no other tube or pipe beyond it. Changes in the length of the prefixed tube have exactly the same effect on the sounds given out as we have seen to arise from alterations in the length of a tube placed below the tongue. In proportion as the prefixed tube is lengthened, the notes given out become deeper and deeper, but not to the extent of an octave. When the lengthening of the tube has reached a certain point, the tone suddenly rises to the original pitch; a further increase of the length of the tube is attended with a fresh deepening of the tones, till again they rise to the same pitch as before; and this alternate sinking and sudden rising of the tones to the original pitch is renewed while the tube is gradually lengthened. There is not, however, a perfect accordance between the length of a tube prefixed to a membranous tongue and that of a tube placed below it, necessary for the production of a given note. In the experiments by which I ascertained these facts, the tongue used was a single lamina of caoutchouc stretched over a tube half an inch in length, with its edge opposed to that of a solid plate of wood, as in the experiments also on the effect of variations in the length of the tube or pipe below the tongue upon the pitch of the sounds. In these experiments a tube which could be lengthened at will was prefixed to the tongue thus arranged, and the tongue was sounded through the medium of this tube. The following table illustrates the comparative effect of variations of length of the tube prefixed to the tongue, and of that placed below it; in the first case there was no tube below the tongue, in the last the air was forced upon the tongue directly from the mouth; in both cases the fundamental note of the tongue alone was the same, the middle B of the treble clef



Sounds with prefixed tube or
"wind-pipe."

Notes.	Length of tube. inch. lines.
A#	4 6.
A	9 10.
G#	13 0.
G	15 6.
F#	17 6.
F	19 0.

Sounds with tube attached below the
tongue.

Notes.	Length of tube. inch. lines.
A#	1 2.
A	2 0.
G#	3 0 to 5 inches 6 lines.
G	7 6.
F#	9 0.
F	10 0.

Sounds with prefixed tube or "wind-pipe."

<i>Notes.</i>	<i>Length of tube.</i> <i>inch. lines.</i>	
F and A#	20 0	(sudden rise of the sound).
A	24 6.	
G#	27 6.	
G	29 0.	
F#	32 0.	
F and A#	35 0	(sudden rise of the sound).
A	37 0.	
G#	42 0.	
G	46 0.	

Sounds with tube attached below the tongue.

<i>Notes.</i>	<i>Length of tube.</i> <i>inch. lines.</i>	
E	13 0.	
D#	17 0.	
A#	22 4	(sudden rise of the sound).
G	23 0.	
F#	25 6.	
F	27 6.	
E	32 0.	
D#	39 6.	
G	40 0	(sudden rise from D# to G).
F#	42 0.	
F	45 0.	

The following were the results of a second experiment, which I detail for sake of comparison with the above. The fundamental note of the

tongues without either tube was E



With prefixed tube.

<i>Notes.</i>	<i>Length of tube.</i> <i>inch. lines.</i>	
D	4 9.	
C#	6 0.	
C	7 6.	
B	9 6.	
A	10 0.	
D	15 9	(sudden rise of the sound).
C#	18 9.	
B	22 0.	
D	24 9	(rise).
C	30 6.	

No further sound could be produced.

With tube attached below the tongue.

<i>Notes.</i>	<i>Length of tube.</i> <i>inch. lines.</i>	
E	1 0.	
D#	3 0.	
D	3 9.	
C#	4 9.	
C	5 6.	
B	6 2.	
A#	7 4.	
A	10 0.	
E to D#	13 6	(sudden rise of the sound).
D	15 0.	
C#	15 3.	
C	17 6.	
B	20 0.	
A	24 0.	
D#	28 0	(sudden rise of the sound).
D	29 6.	
C	30 0.	
B	30 6.	
A#	34 0.	
A	35 0.	
D# to E	41 6	(rise).
C	42 0.	
B	43 6.	

We must lastly mention the changes produced in the sound by contracting the calibre of the tube prefixed to the tongue at either extremity. A plug perforated in the middle for the passage of the air being introduced into that end of a short tube which is nearest to the tongue, a higher note was produced. The effect being the same as that of shortening the tube.

If, on the contrary, the tube was diminished in calibre at the upper extremity,—that most removed from the tongue,—which was done by contracting the lips while blowing, a deeper note was the result, provided the pitch of the instrument had not previously been lowered by lengthening the tube; when the tone had been already rendered much deeper by an increase of the length of the tube, contracting the orifice of the lips either had no effect, or caused even a slight rise of the note.

D. Membranous tongues with both a tube prefixed and one added below the tongue.

The tube prefixed to the tongue, and the tube or pipe placed below it, not only require different lengths for the depression of the pitch of the notes to the same degree; there exists also no relation of compensation between them. In other words, their relative influence is not such, that when a certain length (n) of pipe below the tongue, without any tube above, produces the note x , a smaller length of the pipe ($n-a$), with a prefixed tube of compensating length (a), produces the same note (x). With a pipe below the tongue of $12\frac{1}{2}$ inches in length, for example, the note $F\sharp$ was produced; but with a pipe of $6\frac{1}{4}$ inches, and a tube prefixed to the tongue of $6\frac{1}{4}$ inches, the note was $G\sharp$.

If the two tubes are made respectively of such length that the one with the tongue at its upper extremity (in which the blast is directed from the mouth immediately upon the tongue), and the other with the tongue at its lower extremity (in which the air passes through the tube before striking the tongue), give the same note; the union of both with the same tongue, one above and the other below, will also give the same note. This experiment I have repeated frequently, and constantly with the same result. It would, from this fact taken conjointly with that previously mentioned, (the absence of a compensating relation between the upper and lower tubes,) appear that each tube exerts a special influence on the vibration of the tongue; and that hence, when the tube above the tongue and that below it would, separately combined with the tongue, give rise to different notes, they will also exert distinct influences upon it when both are conjoined with it. The tongued instrument is therefore rendered still more complicated by the addition of the tube above the tongue; and since, whether the instrument be sounded by means of the mouth or by bellows, the cavity conveying the column of air is to be regarded as a prefixed tube, the note produced in the most simple experiment in which a tongue with merely the lower tube is sounded by the mouth, must be modified by the air passing through the cavity of the mouth, &c. It would be of the greatest importance to

know the respective influences of the tube prefixed to the tongue, and of that below it; for, in the organ of voice, the larynx and bronchi represent a tube prefixed to the membranous tongue, — and the cavity in front of the inferior ligaments of the larynx, a tube placed below the tongue. This is, however, one of the most difficult problems in the science of acoustics, and I have not succeeded in arriving at any result which approximates to a law. All I can attain to is a constant confirmation of the observation that the elongation of the prefixed tube, while the lower tube or pipe remains the same, causes a continued change of the note produced, until the two tubes have such comparative length that their respective influence on the sound of the instrument is the same. If the upper tube have a fixed length, the lengthening of the tube below the tongue causes a lowering of the notes to a certain point, when they again rise to the original pitch; a further lengthening of the tube induces a second fall of the notes, till at a certain point they again rise as before; and this gradual falling and sudden rising of the notes is repeated at regular intervals. Thus: in one experiment the tube above the tongue was 6 inches in length, and the fundamental note was D on the fourth line of the treble clef: on a tube 4 inches in length being added below the tongue, the note fell to C $\sharp$; this tube being lengthened to 4 $\frac{1}{2}$ inches, it rose again to D $\sharp$: when the lower tube was 5 inches in length, the note became again lower; and before the length of the tube was 6 inches, it was D $\sharp$. While the length of the tube increased to 8 $\frac{1}{2}$ inches, there was a gradual fall until the note was C $\sharp$, at which it remained until the tube measured 16 $\frac{1}{2}$ inches, when it again rose to D. While the tube was lengthened from 18 to 24 inches, the pitch of the instrument fell again to C $\sharp$; at 27 $\frac{1}{2}$ inches, it rose to D; at 32 $\frac{1}{2}$, it had fallen to C $\sharp$, at which it remained until the tube below the tongue was 4 feet in length.

E. Musical instruments with membranous tongues.

The artificial contrivances, the action of which we have been considering, constitute a peculiar class of reed-instruments, of which no use has hitherto been made in music. The human organ of voice, and the organ of voice in birds, belong, as we shall see, to the same category; the vocal cords being the membranous vibrating tongues.

But the lips also may act as tongues when rendered tense by the contraction of the sphincter oris, which thus compensates for the want of elasticity in the lips themselves. If the breath be forced through the contracted orifice of the lips made tense by the contraction of the sphincter, sounds are produced which belong to the class of sounds

emitted by reed-instruments. The cavity of the mouth and respiratory organs form the "porte-vent" or prefixed tube, and the instrument consists of a reed or tongue with a prefixed tube, but without the lower tube or pipe. If a pipe of pasteboard or metal be added in front of the lips, the sounds produced not only become more sonorous, but may be modified in pitch

The sphincter ani is capable of acting in the same way as the sphincter oris: rendering the skin of the margin of the anus tense, it enables it to vibrate as a tongue, while the rectum filled with gas constitutes a prefixed tube; the pipe below the tongue is wanting.

Allied to the reed-instruments constructed with membranous tongues are the trumpets and horns, in which the lips thrown into vibration by the blast of air act as tongues. In other reed-instruments the reed is a distinct portion of the instrument which yields sounds when separated from the tube. In horns and trumpets, the part called the mouth-piece is incapable of yielding any tone when a current of air is merely blown through it; the lips are necessary to convert the mouth-piece of these instruments into a musical reed. The lips rendered tense by the contraction of the sphincter are thrown into sonorous vibrations of definite value by the current of air forced between them; and the notes produced are higher, the more strongly the lips are contracted by the sphincter. In whistling, the notes become deeper as the opening of the lips is widened; and it at first sight appears that in sounding trumpets also the size of the opening of the lips has an influence on the pitch of the notes; but it is the stronger or weaker contraction of the sphincter muscle, attending the diminution or increase of the size of the opening of the lips, which in this case alters the pitch of the notes, acting in the same way as the increased or diminished tension of the elastic membranous tongues.

The mouth-piece of the trumpet is at its commencement cup-shaped. In sounding the trumpet, the border of the cup-shaped opening is applied to the lips, and the air is forced through the narrow orifice of the lips, the edges of which, rendered tense by the contraction of the sphincter, vibrate like a tongue in the free space afforded by the cup-shaped cavity just mentioned. Hence the necessity of this cavity at the opening of the mouth-piece; if it be filled up so as to leave merely a narrow central passage, the lips firmly pressed upon cease to give any sound. That this is the essential cause of the sound produced in blowing the trumpet, is evident from the fact that a similar sound is heard when the breath is forced merely through the orifice of the contracted lips. One lip is indeed sufficient for the production of such sonorous vibrations; a sound may, for example, be produced by drawing down the upper lip over the surface of the lower lip, and forcing air between them, when the upper lip alone vibrates. The opening of the mouth-

piece of the horn is not cup-shaped, but conical; its use is the same, namely, to allow the edges of the lips to vibrate freely.

The trumpets and horns are classed by M. Biot among the pipes of the flute kind; and the different notes emitted by them are supposed by him to be produced, as in the flutes and mouth-pipes, by variations of the force of the blast. But the pitch of the notes depends really on the degree of tension of the lips, and is little influenced by the force of the blast, which merely affects the loudness of the sound. The trumpets and horns are by M. Muncke classed more correctly among reed-instruments; they are, as we have shown, reed-instruments with membranous tongues, the tone of which is altered in timbre by the metal, and in pitch by the vibrating column of air of the tube. The pitch of the notes, however, does not regularly rise in the inverse ratio with the length of the tube, as in flute-pipes: on the contrary, the effect of the length of the tube in varying the notes is, as in reed-instruments, generally only slight and subordinate. The tube is lengthened to produce this effect in trumpets and horns by the addition of different pieces, crooks, (*Einschiebsel*); in the trombone (*Posaune*) by drawing out the sliding tube. The horns and trumpets have nearly as many supernumerary tubes or crooks as there are "keys" in music. The different notes are produced in these instruments by two other methods: first, by altering the degree of tension of the lips; and secondly, by closing or partially closing the lower extremity of the tube, which in reed-instruments with membranous tongues has, as we have already seen, the effect of lowering the notes. The principal means, however, is the increased tension of the lips by muscular contraction: hence, after long blowing, the player is for a time disabled; and the exertion required is greatest in producing the high notes, not on account of a stronger blast being required for them, but because they are the result of greater contraction of the lips.

The finger-keys closing side-openings in the tube, which have recently been added to the trumpets and horns, have the same influence on the sounds as they have in the clarionet, oboe, and bassoon.

CHAPTER II.

OF THE VOICE, OF THE ORGAN OF VOICE, AND OTHER MEANS FOR THE PRODUCTION OF SOUND IN MAN AND ANIMALS.

THE facts made known in the preceding chapter afford us data for correctly estimating the means which contribute to the production of voice and other sounds in man and animals. We have three principal classes of musical sounds to consider: 1, the voice of man and quadrupeds; 2, sounds formed in the mouth; 3, the voice of birds. These three classes of sound are produced by different instruments and in different parts. The different sounds of the voice in man and mammalia are generated in the larynx, and are somewhat modified in quality by the parts in front of the larynx, through which the air passes. In whistling, we give rise to an entirely different series of sounds, which have their source in the lips and cavity of the mouth. The voice of birds again has another seat; it is produced not in the superior, but in the inferior larynx, which occupies the lower extremity of the trachea at its point of division into the bronchi. In the few other vertebrata below birds which have a voice, as the frogs and toads, the sound is generated in the proper larynx, as in man and mammalia. Besides the organs of voice which prevail extensively through entire classes of animals, there are other special instruments of sound in some animals, even among the lower classes; the examination of these, however, would lead us too far from our proper object.*

1. *Of the human voice.*

A. *Of the human organ of voice.* — If any question relating to the human voice have been determined with certainty, it is that regarding the part of the air-passages in which the voice is formed.

* The authors who have written concerning the human voice are: Dodart, *Mém. de l'Acad. de Paris*, 1700, 1706, 1707. — Ferrein, *ibid.* 1741. — Magendie, *Précis élément. de Physiol.* — *Physiology* translated by Milligan. — Biot, *Précis Element. de Physique experiment*, Paris, 1824, t. i. p. 457. — Fechner, in his translation of Biot's *Experimental-physik*. ii. p. 149. — Savart, in *Magendie's Journ. de Physiol.* v. — Liscovius, *Theorie der Stimme*. Leipz. 1814. — Chladni, in *Gilbert's Ann.* lxxvi. p. 187. — Mayer, in *Meckel's Archiv*. 1826. — Bennati, *Recherches sur le Mécanisme de la Voix Humaine*, Paris, 1832. — Muncke, in *Gehler's Physik. Wörterbuch*, viii. 373. — Mayo, *Outlines of Human Physiology*. — Sir C. Bell, *Philos. Transact.* 1832, pt. ii. — Malgaigne, *Arch. Gén. de Méd.* 25. — Willis, *Transact. of Philos. Soc. of Cambridge*, 1832. — Bishop, in *Lond. and Edinb. Philos. Magaz.* 1836. — Lehfeldt, *Diss. de Vocis Formatione*, Berol. 1835. On the voice of birds, see Cuvier, *Anat. Comparée*; and Savart, *Froriep's Not.* 331, 332.

Observations on living subjects, as well as experiments on the larynx taken from the dead body, prove that the sound of the voice is generated at the glottis, and neither above nor below this point. If an opening exists in the trachea in the human subject, or if an opening is made in this situation in an animal, the sound of the voice ceases, but returns on the opening being closed. This experiment has been often made, and its accuracy is beyond a doubt. An opening into the air-passages above the glottis, on the contrary, does not prevent the voice being formed. M. Magendie, moreover, has convinced himself that the voice is not lost, though the epiglottis, the superior ligaments of the larynx, and the upper part of the arytenoid cartilages be injured. He has also seen in living animals, whose glottis he had laid bare, that during the emission of sound the inferior ligaments of the larynx, which bound the fissure of the glottis, were thrown into vibration. We know also that injury of the laryngeal nerves supplying the small muscles, which alter the states of the aperture of the glottis and make tense the vocal cords, puts an end to the formation of vocal sounds; and that, when these nerves are divided on both sides, the loss of voice is complete. Again, if we attempt to produce sounds by forcing a current of air from the trachea through the larynx in the dead human subject,—an experiment in which a person the most unpractised may succeed, provided the vocal cords be in some degree tense and the aperture of the glottis narrowed,—we shall find that the sounds are produced, whether the part of the trachea which serves to convey the current of air to the larynx be long or short; and even though it be entirely wanting, and the air be forced immediately through the glottis from the lower extremity of the larynx. Again, a larynx thus cut from the body may be freed from all the parts lying in front of the glottis: the epiglottis, the upper ligaments of the larynx, the ventricles of the larynx between the superior and inferior, or vocal ligaments, the greater part of the arytenoid cartilages, namely, their upper part, may be all removed; and if the inferior ligaments or vocal cords only remain, and be approximated so that the fissure of the glottis be narrow, clear tones will be produced by forcing air through it from the trachea. All these facts establish the correctness of the view which regards the glottis and the inferior laryngeal ligaments or vocal cords which form the immediate boundaries of the glottis as the essential source of the voice; the trachea as the “wind-chest”* of the wind instrument; and the vocal tube in front of the glottis, comprehending the upper part of the cavity of the larynx, and the air-passages thence upwards to the openings of the mouth and nostrils, as the tube of a musical instrument by which the sound may be modified, but not generated.

* [“Wind-chests” are the reservoirs of air in the organ, whence the wind is distributed to the pipes, when the keys or pedals are pressed down.]

The parts forming the boundaries of the glottis, namely, the vocal cords, (fig. 58, 3,) first claim our attention. They are elastic, and can be made tense by the depression of the thyroid cartilage (figs. 57 and 58, 8),

Fig. 57.*

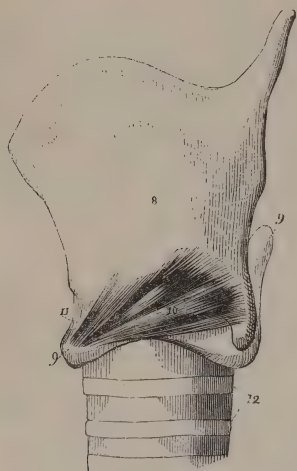


Fig. 58.†



towards the cricoid cartilage (figs. 57 and 58, 9), by means of the crico-thyroid muscles (fig. 57, 10), as well as by the retraction of the arytenoid cartilages (fig. 58, 2), which are moved backwards by the posterior crico-arytenoid muscles (fig. 58, 4), at the same time that they are approximated to each other by the musculi arytenoidei (6). The effect of these movements of the thyroid and arytenoid cartilages is, as we have said, to make tense the vocal cords, either by the depression of the thyroid cartilage, the arytenoid cartilages having been previously fixed by their muscles, or by the retraction of the latter, after a fixed point has been obtained by the movement of the former. The length of the fissure of the glottis depends on the degree to which the cords are thus stretched. The aperture of the glottis is narrowed by the approximation of the arytenoid cartilages, which is effected by the musculi

* [Fig. 57. Lateral view of exterior of larynx, after Mr. Willis.—8. Thyroid cartilage. 9. Cricoid cartilage. 10. Crico-thyroid muscle. 11. Crico-thyroid ligament. 12. First rings of trachea.]

† [Fig. 58. Bird's-eye view of interior of larynx.—1. Aperture of glottis. 2. Arytenoid cartilages. 3. Vocal cords. 4. Posterior crico-arytenoid muscles. 5. Lateral crico-arytenoid muscle of right side, that of left side removed. 6. Arytenoid muscle. 7. Thyro-arytenoid muscle of left side, that of right side removed. 8. Thyroid cartilage. 9. Cricoid cartilage. 13. Posterior crico-arytenoid ligament. With the exception of the arytenoid muscle, this diagram is a copy from Mr. Willis's figure.]

arytenoidei; it is dilated by means of the musculi crico-arytenoidei postici, which draw the arytenoid cartilages asunder. The vocal cords, by virtue of their elasticity, are capable of being thrown into regular vibrations, after the manner of membranes extended longitudinally from two extremities (see page 988). Their elasticity is due to the elastic tissue which composes them, and which is also found in many other parts of the body (see page 875).

The vocal cords are not, however, the only parts of the larynx composed of elastic tissue. The ligamentum hyo-thyroideum and the ligamentum crico-thyroideum medium have been long known as yellow elastic ligaments. The last-named ligament must by its elasticity, and quite independently of any action of the crico-thyroid muscle, keep the corresponding borders of the cricoid and thyroid cartilages approximated to each other, and will therefore offer some resistance to the movement of the arytenoid cartilages backwards in the act of producing tension of the vocal cords, a certain degree of which will be produced by the elasticity of this ligament alone when the arytenoid cartilages are fixed by their muscles. A much wider distribution still of the elastic tissue in the larynx has been pointed out by M. Lauth.* The principle portion of the elastic tissue arises, according to M. Lauth, from the lower half of the angle of the thyroid cartilage between the insertions of the thyro-arytenoidei muscles. Thence the fibres radiate downwards, obliquely backwards, and even somewhat upwards, forming a continuous membrane, which is attached to the entire upper border of the cricoid cartilage, except at the situation of the arytenoid cartilages, where the fibres become connected with the anterior angle of the basis of those cartilages and with their anterior border. This radiating elastic membrane has three accessory fasciculi; one, which passes downwards, is the crico-thyroid ligament; the other two are the inferior thyro-arytenoid ligaments, or vocal cords. This elastic membrane forms also the superior ligaments of the glottis, which are connected with the inferior or true vocal cords by an extremely thin expansion of elastic tissue covering the ventricle of the larynx. The hyo-thyroid ligament also is elastic; and the same tissue exists likewise in the thyro-epiglottic, hyo-epiglottic, and glosso-epiglottic ligaments. If we add to these parts the elastic longitudinal fibres in the membranous part of the trachea and bronchi, we shall have an idea of the great extent of the tissues susceptible of consensual vibration and resonance in the parts surrounding the organ of voice.

The next point to be considered is the variety of forms which the aperture of the glottis (fig. 58, 1) is capable of assuming, and which it

* Mém. de l'Acad. Roy. de Méd. 1835.—Müller's Arch. 1836.—Jahresbericht, p. clvii.

really assumes at the time of emitting sound. According to M. Lauth's résearches, the glottis is able to take the following different forms. In the passive state, when emitting no sound, the aperture of the glottis is lance-shaped; it dilates somewhat, as is already known, during inspiration, and becomes narrowed again during expiration. The lateral boundaries of the aperture are, posteriorly, the inner surface and anterior process of the base of the arytenoid cartilages (fig 58, 2); anteriorly, and in the greater extent, the vocal cords (3), which are connected posteriorly to the above-mentioned anterior process of the basis of the arytenoid cartilages. The whole length of the aperture of the glottis when open is eleven lines, of which the posterior part between the arytenoid cartilages and their anterior process measures four, the anterior part between the vocal cords seven lines. When dilated to its full extent (by the *mus. crico-arytenoidei postici*) (4), the aperture of the glottis has the form of a lozenge, of which the posterior angle is truncated. The lateral angles correspond to the anterior processes of the base of the arytenoid cartilages, which may be separated from each other to the distance of $5\frac{3}{4}$ lines. In the contracted state, the *rima glottidis* may have either of three forms. The anterior processes of the base of the arytenoid cartilages may be approximated to each other through the agency of the lateral crico-arytenoid muscles (5), and by coming into contact may divide the fissure of the glottis into two parts; or the *rima*, though narrowed, may remain open in its whole length; or, lastly, the posterior part of the *rima* may be quite closed by the approximation of the arytenoid cartilages themselves, together with their anterior processes, to which the *chordæ vocales* are attached. The movement of the arytenoid cartilages, which produces this last form, is effected by the united action of the proper arytenoid muscles (6) and of the lateral crico-arytenoid (5). The *rima glottidis* is here confined to the space between the sharp borders formed by the elastic vocal cords; it comes to a point both anteriorly and posteriorly; its length and breadth vary here very much, according as the vocal cords are stretched or not. The relaxation and shortening of the vocal cords are effected by the thyro-arytenoid muscles (7), which also are able to diminish the transverse diameter of the space above and below the vocal cords.

The form of the *rima glottidis* in the human subject during life, at the moment of the emission of sound, is not at present very accurately known; but that it becomes narrowed is certain. The anterior portion of the aperture,—that bounded by elastic and sharp borders,—being alone susceptible of sonorous vibration from the action of the current of air, the posterior part of the opening, which cannot contribute to the original production of sound, can only by considerably increasing the area of the opening disturb the action of the air on the other part.

Mr. Mayo* has made some observations on the movements of the glottis in the human subject during life. A man in an attempt to commit suicide divided the larynx immediately above the chordæ vocales; in consequence of the oblique direction of the wound the vocal cord and arytenoid cartilage of one side were wounded. During undisturbed respiration, the form of the aperture of the glottis was triangular. As soon as a sound was uttered, the chordæ vocales became almost parallel, and the rima glottidis took a linear form. It would appear from the figure that the posterior part of the aperture was not closed. In another patient the incision passed into the pharynx above the thyroid cartilage, rendering the upper part of the arytenoid cartilages visible. During the emission of sound the arytenoid cartilages kept the same position as when the glottis was closed. Kempelen† has stated, that the glottis, to produce sound, must be approximated to within $\frac{1}{12}$ th, or at most $\frac{1}{10}$ th, of its diameter; and Rudolphi‡ confirms this statement, from the observation of the parts in a man whose pharynx was by the absence of the nose laid so open to view that the opening and closing of the glottis could be readily seen.

M. Magendie excludes from the glottis the space between the arytenoid cartilages, which he has found in experiments on animals to be closely applied to each other during the emission of sound. Malgaigne has made the same observation. This may possibly be generally the case; and sounds cannot be readily elicited from the human larynx removed from the body, when the posterior portion of the glottis is not closed. Nevertheless it is not, according to my experiments, absolutely necessary; I have, in some rare cases, been able to produce a sound artificially, when the chordæ vocales were made somewhat tense and the aperture of the glottis narrowed, though open in its whole length.

B. Of the modulation of the voice, and the causes on which it depends.
—Experiments on living animals have hitherto afforded few results calculated to elucidate the physiology of the human voice, notwithstanding the labours of MM. Magendie and Malgaigne, which are in a certain measure valuable. M. Magendie laid bare the glottis in a dog by means of an incision between the thyroid cartilage and os hyoides; he then observed that the vocal cords, during the utterance of deep notes, vibrated in their entire length, but that the portion of the rima glottidis which lies between the arytenoid cartilages was closed. During the utterance of very high notes, the vibrations were perceptible only in the most posterior part of the vocal cords, and the air

* Outlines of Physiol. 1837, p. 371.

† Mechanismus d. Menschlich. Sprache. Wien. 1791, p. 81.

‡ Physiologie, ii. I. 370.

escaped only through that part of the rima glottidis. It is difficult to understand how the closing of the anterior part of the glottis could be effected. Such a change in the glottis, causing the air to be transmitted only through the posterior part, cannot be imitated in the human larynx; while, on the contrary, it is not difficult to shorten the fissure of the glottis at its posterior part by approximating the anterior processes of the arytenoid cartilages to which the vocal cords are attached, the tension of these cords still remaining the same. Careful experiments on the human larynx itself, after its removal from the body, offer the best prospect of useful results.

Experiments on the separated larynx are in first attempts attended with extreme difficulty; all the parts are moveable, and it is not at first apparent how the uniform tension and the uniform fixed position of the cartilages, so necessary for attaining any degree of accuracy in the experiments, can be given; and at the same time how the position once given can be made capable of alteration as the experiment may require. With a little contrivance, however, these objects can be accomplished. The first thing to be done is to obtain a fixed point in the larynx. The anterior wall is naturally mobile in the greater part of its extent, and the posterior wall at its upper part. The thyroid cartilage can be moved towards the cricoid cartilage, and the arytenoid cartilages also; and by either movement the vocal cords are rendered tense. The arytenoid cartilages being the most moveable parts, and those by the wrong position of which an error in the experiments might most easily be caused, my first aim is to fix them. With this view I pass an awl or pin transversely through their base; doing this with very great care, in order that, when afterwards extended, the two vocal ligaments may have an equal degree of tension; and also making the transfixion in such a manner that, when the two cartilages are approximated on the pin, the anterior processes at their base may touch each other. The larynx, with a small portion of the trachea attached, being thus prepared, is fixed, with its posterior wall downwards, to a board by means of the cricoid cartilage; and the pin which transfixed the arytenoid cartilages (these being put into any position or degree of approximation that may be wished) is also firmly tied down to the board. The posterior wall of the larynx being thus fixed, any degree of tension required may be given to the vocal cords by exerting traction on the anterior wall formed by the thyroid cartilage. To avoid the resistance which might be offered by the attachment of the thyroid to the cricoid cartilage, it is well carefully to separate their connections. As a means of drawing away the thyroid cartilage from the posterior wall of the larynx, and thus of making tense the vocal ligaments, I fix a thin cord to the angle of the thyroid cartilage immediately above the attachment of the ligaments, and passing it over a pulley connect with it a scale;

by putting different weights into this scale I can accurately regulate the tension exerted. The epiglottis, superior ligaments of the glottis, the ventricles of the larynx, the capitula laryngis of Santorini, the ligamenta aryteno-epiglottica, and even the upper portion of the thyroid cartilages, not being essential to the production of the vocal sounds, are all cut away to render the vocal cords and aperture of the glottis more easily visible. Besides, it is necessary to determine first what can be effected by the vocal cords alone, before investigating the influence of the superior part of the cavity of the larynx. A wooden tube for the experimenter to blow through is inserted into the portion of trachea left attached to the larynx.

The *results of experiments* performed by means of the contrivance above described and frequently repeated are as follows:

By blowing from the trachea through the aperture of the glottis narrowed by the approximation of the vocal cords, clear and full tones, which come very near to those of the human voice, are produced.* These tones emitted by the lower ligaments of the glottis alone differ from those heard when the upper ligaments and the epiglottis are not removed, merely in the latter being louder; the parts of the larynx last mentioned being, when present, as well as the posterior wall of the trachea, thrown into strong vibrations whenever the vocal cords vibrate. The sonorous vibrations of the vocal cords are produced most readily and certainly when the posterior part of the glottis—that part between the arytenoid cartilages—is closed. This disposition is, however, not absolutely necessary; for, although Magendie and Malgaigne have asserted the contrary, sounds may frequently be produced when the glottis is open in its whole length: still these sounds are feeble, and produced with difficulty. If the arytenoid cartilages be approximated in such a manner that their anterior processes touch each other, but yet leave an opening behind them as well as in front, no second vocal tone is produced by the passage of the air through the posterior opening, but merely a rustling or bubbling sound.

The height or pitch of the note produced is the same whether the

* Very similar sounds may be produced also by blowing through a tube, on the end of which there are two bands of moist elastic arterial tissue stretched by their extremities only, but closing the whole end of the tube with the exception of a slight fissure between them. The best kind of artificial larynx is, in fact, thus formed: moist bands of the middle arterial coat being composed of the same tissue as the vocal ligaments, and having the same physical properties. Other materials, as caoutchouc, may be substituted for the moist arterial tissue, and the sounds will not be very different. The moist elastic bands have the advantage, however, of yielding good sounds, even when reduced to a very small size; in which respect they bear a stronger resemblance to the true vocal ligaments, and are not subject to the objection made by Cagniard la Tour, who observed that the laminæ of caoutchouc were not comparable to the natural vocal cords in that respect. (Magendie's *Physiologie*.)

posterior part of the glottis be open or not, provided the vocal cords maintain the same degree of tension; the closing of the posterior part of the glottis must not, however, extend at all further forwards than the point of attachment of the vocal cords to the base of the arytenoid cartilages. The width of the aperture of the glottis also, as Ferrein observed, has no essential influence on the height of the note as long as the vocal cords have the same tension; the tone is merely, as in the case of caoutchouc tongues (see p. 989), more difficult to produce, and is less perfect, the rushing of the air through the aperture being heard at the same time.

When the tension of the two vocal cords is unequal, there is generally produced but one sound; in some rare instances, however, as in the case of the caoutchouc tongues, two notes are heard. Frequently, also, as we observed with regard to the tongues of caoutchouc, one vocal cord is seen to vibrate alone; this is particularly the case when the two cords are not on the same level. Sometimes, when the tension of the two cords is quite equal, instead of the proper fundamental note, a much sharper sound is heard; this happens especially when the cords come into contact with each other at some point during their vibrations, and is to be attributed to the production of nodal points. The same thing occurs sometimes in experiments with caoutchouc tongues.

Vocal sounds can be produced not only when the lips of the glottis are separated by a narrow interval, but even when they are quite in contact, especially if the chordæ vocales are much relaxed; in which case the vibrations of the lips of the glottis are very strong. The same thing is observed in experiments with tongues of caoutchouc.* The notes emitted in such a condition of the glottis,—namely, when the vocal cords are in contact, and their tension at the time slight,—are stronger and fuller; but provided the length of the cords be the same, and the tension in both cases equally slight, the height of the note is not influenced by the cords being in contact, or by their being separated by a narrow interval.

The vocal cords can without difficulty be made to sound even when quite relaxed, provided the glottis be much shortened; for example, by pressing together the lips at their posterior part by means of forceps. Even when the length of the glottis is thus diminished to two lines, notes can still be obtained from it; but then the vocal cords must be relaxed and their edges in contact. This production of sound by very relaxed and shortened cords cannot be imitated with caoutchouc tongues; but it may with moist bands of elastic tissue, such as that of the middle coat of arteries. Elastic tissue, even when much

* The caoutchouc tongues often produce sounds when quite in contact with each other, and even still more readily when the border of one overlaps that of the other; or when the border of a single caoutchouc lamina lies upon the border of a thin plate of wood.

relaxed and destitute of tension, is still capable of reacting by virtue of its elasticity against the current of air; the air distends the lax lips of the glottis, when this is very short, to such a degree as to enable them to react, and the vibrations thus produced have so extensive a sphere that the glottis is alternately opened and shut. It is not, however, necessary that the chordæ vocales should be rendered so elastic by distension that in their vibrations they should periodically close the glottis; they may vibrate while they are still kept distended by the current of air, without being restored by their elasticity to the straight line.

The height of the notes is regulated by the length and tension of the vocal cords. The notes are, *cæteris paribus*, lower in pitch in proportion to the length of the glottis; but deep notes may be obtained from a glottis much shortened by its lips being pressed together with forceps, if the vocal cords be at the time relaxed; and a very long glottis will yield high notes, if the chordæ vocales have a great degree of tension. The effect of increasing tension of the chordæ vocales on the sound emitted from the glottis while open in its entire extent from the angle of the thyroid cartilage to the attachment of the cords to the anterior process of the arytenoid cartilages, which are in contact, does not altogether accord with the effects of increasing tension on the sounds obtained from strings and membranous tongues extended from two opposite points. The increase in the height of the notes, or in the number of vibrations produced in strings of uniform length, takes place, we have seen (p. 975), in a direct ratio with the square roots of the extending forces. For example, if a string extended by a force equal to the weight of four loth* give the note C, it will, when the force is increased to sixteen loth, yield the octave of C; and when the extending force equals sixty-four loth, the note produced will be the second octave of C. But, on repeating similar experiments with the human larynx, it is found that the notes obtained, when the extending force is increased in the ratio of four, sixteen, sixty-four, are not the octaves of the original note, but generally a semitone or a tone, three semitones or two or three tones, lower than the octaves. Still the series of notes correspond sufficiently in the number of vibrations to the numbers one, two, four, to prove the analogy between the laws regulating the notes of the human organ of voice and those of strings and membranous tongues (see Appendix). The experiments by which this result is obtained are extremely difficult to perform, from the necessity of giving the two vocal cords as nearly as possible the same degree of tension, and of preventing the two cords from coming in contact at aliquot parts of their length, by which harmonic notes would be produced. A single vocal cord separated from the larynx with merely portions of the

* [A loth is about half an ounce.]

thyroid and arytenoid cartilages attached, being fixed to a board by one extremity, while by the other it is extended by a cord passed over a pulley and suspending a scale with weights, can also be made to emit a sound by blowing upon it through a fine tube, as in the experiment on caoutchouc tongues (see p. 988); and the notes thus produced also follow nearly, but not exactly, the law regulating the notes of strings extended by varying forces. The notes are somewhat lower than they should be according to that law.

The compass of the notes which may be produced by varying the longitudinal tension of the vocal cords is about two octaves; when the tension is carried further than this, the notes become disagreeable, shrill, and whistling or shrieking. If the different degrees of tension of the ligaments cannot be produced by extending them in a line with their own direction by means of a cord passed over pulleys, it may be done very easily by drawing down the thyroid cartilage towards the cricoid, which is the mode adopted by nature: while a person singing is gradually raising his voice from low to high notes, the space between the thyroid and cricoid cartilages in front can be felt with the finger to be diminished (by the agency of the crico-thyroid muscles). In the experiments which I performed in this manner (see Appendix), the weight required to raise the lower notes a semitone was about half a loth; but as the tension became greater, and the notes higher, it required more and more, and at last three loths, to raise the notes the same extent. The effect of the same weight is of course different according to the change in the position of the thyroid cartilage; and the elasticity of the vocal cords will by long tension be diminished, but the effect thus produced is slight. The weight of about one pound, and a corresponding degree of muscular power, is required to raise the notes through the compass of two octaves.

If, while the posterior part of the glottis is closed, and the arytenoid cartilages fixed, a more complete relaxation of the vocal cords be induced by approximating the thyroid to the arytenoid cartilages (by means of a scale with weights suspended by a cord passing over a pulley behind the larynx, which is placed perpendicularly, the crico-thyroid ligament having previously been divided to remove all tension which it might produce), still deeper notes can be obtained. We in fact imitate by such a mechanism the action of the thyro-arytenoid muscles. By blowing upwards through the glottis thus arranged, by means of a curved tube, while the weight which diminished the tension of the cords was gradually increased, I was able to produce the deepest bass notes (see Appendix).

Two perfectly distinct series of tones can be produced in a larynx separated from the body, when the tension of the vocal cords is very slight: one of these series of tones has the most perfect resemblance

to the tones of ordinary voice ; the notes of the other series are generally higher than those of the former, and are the highest that can be produced ; they are in every respect similar to the falsetto notes. When the vocal cords have a certain degree of tension, both these kinds of tones may be produced ; sometimes one kind, and sometimes the other is heard. A certain tension of the cords is always productive of notes with the falsetto tone, whether the air be blown through the glottis forcibly or feebly. When the vocal ligaments are much relaxed, the tones are always those of ordinary voice, however feebly or forcibly we blow. If a slight tension of the ligaments is maintained, it depends on the manner of blowing whether the note be of the ordinary tone or falsetto ; (the falsetto note being most easily produced by blowing very gently :) and the two different notes thus produced may be very distant from each other in the musical scale, even as much as an octave. For experiments on the two registers of vocal sounds, the ordinary notes and the falsetto, it is better to take the male larynx. The posterior part of the glottis should be closed as before, and the whole larynx fixed perpendicularly as in the last-mentioned experiments. The degree of tension necessary for producing either kind of note is given by the mere elasticity of the crico-thyroid ligament ; if greater force be applied to render tense the vocal cords, the ordinary vocal sounds can no longer be produced. It was first observed by Liscovius that the vocal cords are lax while the ordinary sounds are produced, and tense during the emission of the falsetto notes : but the mere tension of the vocal cords is not the cause of the difference of these notes, for there is a certain state of the cords in which, by varying the mode of blowing either the one or the other kind of note may be produced ; and the different height of the notes of the natural voice is owing to the different degrees of relaxation of the vocal cords, and not, as he supposed, to the degree of width of the rima glottidis. The real cause of the difference between the falsetto and the notes of the natural voice is, that for the former merely the thin border of the lips of the glottis vibrate, while for the latter the whole breadth of the vocal cords are thrown into strong vibrations which traverse a larger sphere. This fact was first observed by Lehfeltdt. The falsetto notes have been compared by Gottfr. Weber* to the harmonic notes of strings, and supposed, like them, to be produced by the vibration of the vocal cords in segments separated by nodal points ; but it is evident that they are not thus produced, for when the vocal cords have that very slight degree of tension which permits either the notes of the natural voice or falsetto notes to be produced by different modes of blowing, it can be seen that the vocal cords, as well when the falsetto notes as when the others are heard, vibrate in their whole length ; and the real difference is perceived to be, that for the falsetto notes the vocal ligaments vibrate only at their border, and the

* Cœcilia, i. p. 81.

fissure of the glottis is then generally defined and distinctly visible, while for the other notes the whole vocal bands vibrate in their entire breadth, and the arc of the vibrations is so extensive that the appearance produced by the motion of the two lips becomes confused, and obscures the fissure of the glottis: indeed, not only the vocal cords themselves vibrate, but also the adjoining membrane immediately below them, as well as the lower and stronger part of the thyro-arytenoid muscle, which lies external to the lining membrane of the larynx at that part.

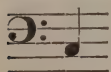
The deeper notes of the natural voice are produced, as we have already seen, by approximating the thyroid to the arytenoid cartilages; but, when the relaxation of the vocal cords thus effected passes a certain point, vocal sounds cease to be heard. By gradually drawing away the thyroid again from the arytenoid cartilages in a good male larynx, series of bass notes from the deepest upwards to the extent of an octave are produced; but, when the vocal cords have acquired a certain degree of tension, the notes assume the falsetto character. There are, however, two other modes of producing high notes, without increasing the tension of the vocal ligaments so much as to cause them to give out falsetto tones. One is to blow with greater force, by which means the notes may without difficulty be raised through a series of semitones the extent of a "fifth;" but the higher notes thus produced are unpleasant to the ear, shrieking and harsh (see Appendix). The other mode of raising the notes consists in narrowing the diameter of the larynx immediately below the inferior ligaments, or vocal cords.

The great importance of this part of the larynx, which gradually contracts until it terminates superiorly in the glottis, has not hitherto been recognised; though the mere circumstance of its being invested externally at each side, to the extent of some lines, by the thick portion of the thyro-arytenoid muscle, ought to have directed attention to it. If the thyro-arytenoid muscles be dissected away in a male larynx, prepared as already described, and the membrane of the larynx pressed inwards on each side by means of the flat handles of two scalpels, so as to narrow the part of the cavity of which we are speaking without pressing on the vocal cords themselves, the notes produced by blowing will, *cæteris paribus*, be higher, and at the same time be prevented more than by any other method from assuming the falsetto character. The lower portion of the thyro-arytenoid muscles must during life have a similar action; and the influence of the narrowing of the larynx at this part on the height or acuteness of the notes is analogous to the effect of diminishing the calibre of the tube prefixed to a tongue of caoutchouc at the part nearest to the tongue (see p. 997).

The thyro-arytenoid muscle has, however, other uses. It extends upwards at the side of the vocal cords, with the exterior fibres of which

it is intimately connected, as far as the side of the ventricles of the larynx, and can act as a damper upon the vibrations of the membranes at that part, and indeed upon the outer part of the vocal ligaments themselves; the effect of which would be, as we have seen in experiments on the caoutchouc tongues (see page 991), a sharpening of the tones. A third action of these muscles will be to modify the tension of the vocal ligaments by virtue of the connection with their fibres pointed out by Lauth, which I have verified. The vocal cords, when relaxed as for the production of deep notes, will be rendered tense by the contraction of the thyro-arytenoid muscles, in the same way that the lips in horn-blowing are affected by the action of the sphincter oris.

The action of the thyro-arytenoid muscles may be imitated by compressing laterally the thyroid cartilage (which for this experiment must not be ossified). By so doing, the artificial notes may be raised to as high a pitch as the human voice is generally capable of reaching with ease; and, if the vocal cords be not tense, falsetto tones are not produced. The deepest note which I could produce in one of my experiments by relaxing the vocal cords was the middle C of the bass clef



; by producing slight tension of the cords, and blowing with

greater force, I could produce the octave above this (C^1), but I could in that way raise the notes no higher; by compressing the larynx laterally, however, about the situation of the vocal cords and below them, I was able to produce a series of higher notes to the extent of another octave (C^2) without any falsetto tone, although under other conditions falsetto notes could be produced from the $A\sharp$ below the second C (C^1) upwards. The prevention of the falsetto notes, which was here attained by the lateral compression of the larynx, seems during life to be effected by the action of the thyro-arytenoid muscles.

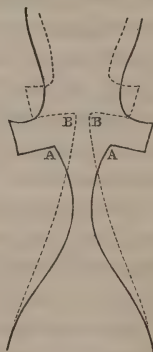
According to the foregoing observations, the following will be the mode of production of the notes of the natural voice: — The vocal ligaments vibrate in their entire breadth, and with them the surrounding membranes and the thyro-arytenoid muscles. For the deepest notes, the vocal ligaments are much relaxed by the approximation of the thyroid to the arytenoid cartilages. The lips of the glottis are, in this state of the larynx, not only quite devoid of tension; they are, when at rest, even wrinkled and plicated; but they become stretched by the current of air, and thus acquire the degree of tension necessary for vibration. From the deepest note thus produced the vocal sounds may be raised about an octave by allowing the vocal cords to have the slight degree of tension which the elastic crico-thyroid ligament can give them by drawing the thyroid cartilage towards the cricoid. The

medium state, in which the cords are neither relaxed and wrinkled nor stretched, is the condition for the middle notes of the natural register, those which are most easily produced. (The ordinary tones of the voice in speaking are intermediate between these and the deep bass notes.) The higher notes are produced, and the corresponding falsetto tones avoided, by the lateral compression of the vocal cords, and by the narrowing of the space beneath them (the *aditus glottidis inferior*) by means of the thyro-arytenoid muscles, and further by increasing the force of the current of air. The muscular tension given to the lips of the glottis by the muscles above-mentioned must also be taken into account as contributing to the production of the notes of the natural register.

The falsetto notes are produced by the vibration of the inner portion or border of the vocal ligaments; their variation as to height or sharpness being effected by variation of the tension of the ligaments.*

* [To the above account of the conditions of the glottis and vocal cords necessary for the production of the different sounds of the voice, we may here append some observations on the same subject by several English physiologists. A very interesting paper by Mr. Willis, in the *Transactions of the Cambridge Philosophical Society*, 1832, (read May 1829,) contains some original views as to the position of the lips of the glottis during the production of voice. Mr. Willis compares the vibrating lips of the glottis to elastic membranes (of leather or caoutchouc) of which the upper edge is free and the other edges confined, and of which the planes have the same direction as the tube through which the current of air causing their vibration passes. (Professor Müller regards the vocal ligaments as analogous to membranous plates placed transversely to the direction of the tube, with their edges opposed.) Mr. Willis shows, that elastic membranes, such as we have described, do not vibrate or give rise to sound when inclined either inwards or outwards from the direction of a current of air passing between them; but that when placed parallel, or nearly so, to each other and to the current of air, they vibrate, and emit a loud musical sound. These facts he applies to the explanation of the production of voice by the vocal cords. In the ordinary position of the glottis, during respiration without vocalization, he supposes that the lips of the glottis are inclined from each other, (as at A, fig. 59, which is an imaginary transverse perpendicular section of the vocal tube,) and that to produce voice they must assume the parallel state (as at B, fig. 59). He attributes the different notes of the human voice to different degrees of tension of the vocal ligaments, since laminae of leather, and, still better, caoutchouc, will, he shows, yield a variety of notes according to the degree of tension given them. But it is not tension alone, he argues, which enables the lips of the glottis to produce sounds. For as the size of the space between the thyroid and cricoid cartilages, felt externally, indicates the tension of the vocal ligaments,—being small when they are tense and high notes produced, and large when the ligaments are

Fig. 59.



The observations which we have detailed also prove clearly that neither the epiglottis, the superior ligaments of the glottis, the ventricles of the larynx, nor, in fact, any of the parts in front of the vocal cords, are necessary for the production either of the notes of the natural voice or of the falsetto notes.

The notes which are easily elicited from the *female larynx* are generally higher than those from the *male larynx*, though by complete relaxation and approximation of the vocal cords the female larynx can be made to yield deep tones. The principal cause of this is, that the vocal cords are in general much shorter in the female larynx; although the smaller size of the cavity of the larynx, and the less thickness of its walls, affording less means of resonance necessary for the low notes, have also a great influence. On the same principles we must explain different kinds of male voices, the bass and tenor; and of female voices,

relaxed for the production of bass notes,—and as the medium size of this space, proper for the production of intermediate notes, does not differ from that which it has in the state of rest, when no voice is uttered, he infers that in that state the ligaments possess the tension required for the average pitch of speech, but have not the necessary parallel position. That the production of voice does not depend on diminishing the size of the aperture of the glottis he thinks certain, “because we can make the aperture of the passage pass through all degrees of contraction up to absolute closing during the expiration of the breath, without producing any sound, except the usual rushing noise of a forcible current of air passing through a narrow aperture.” Mr. Willis attributes to the thyro-arytenoid muscles the office of placing the arytenoid cartilages and the lips of the glottis in the vocalizing position.

Mr. Mayo has observed, in cases of wound of the pharynx, (as is stated in the text at page 1007,) that the edges of the glottis are in contact during the utterance of vocal sounds; and this state of the glottis, together with a certain degree of tension, he believes to be the condition for vocalization. The vocalizing position pointed out by Mr. Willis, he conceives to be the necessary result of the vocal ligaments being on the stretch.—Mayo’s Physiology, Ed. 4th, p. 370.

Mr. Bishop states, as the result of experiments on the larynx after death, “that, in order to produce any sounds whatever, it was requisite to close the chink of the glottis by bringing the edges of the vocal ligaments into immediate contact, when, by straining them tolerably tight, the sounds became loud and distinct.” He also remarked, “that when the gravest tones were uttered, the ligaments vibrated throughout their whole length; and that, as the tones became more acute, a proportionally smaller extent of the ligaments was thrown into vibration.” This observation accords with those of M. Magendie in experiments on living dogs (see page 1007). “During the production of the most acute tones,” Mr. Bishop says, “the tension of the vocal ligaments was but slightly increased, and the greatest possible tension was insufficient to produce acute tones, whilst these ligaments vibrated throughout their whole length.” The latter observation is opposed to the results of Professor Müller’s experiments. Mr. Bishop ascribes to the thyro-arytenoid muscle the power, not only of rotating the lips of the glottis into the vocalizing position described by Mr. Willis, but also of forcing them into contact with each other during its contraction; and to the thyro-arytenoid and crico-thyroid muscles the power of so affecting the vocal cords “that a portion of them only is rendered susceptible of vibration.”—London and Edin. Philos. Mag. 1836.]

the alto and soprano. The male voice is, it is true, capable of being raised to high notes by great tension of the cords, but the tones thus produced are of the falsetto character; notes of the same height can be produced with ease by the shorter vocal cords of the female larynx with less tension. Moreover, there must be a limit to the tension of the male chordæ vocales, on account of muscles being able to shorten themselves by contraction only to a certain extent; the maximum of shortening of which they are susceptible is, according to M. Schwann, only about one-third of their length. The means of rendering tense the vocal ligaments are somewhat greater than this calculation would indicate, since the vocal cords can be acted on by muscles both before and behind; and the cartilages to which the cords are attached are capable of a lever-like movement. Still there must be a limit to the raising of the pitch of the voice attained in this way. A still higher but feeble note may be accidentally produced, while the vocal cords are tense, by their coming into contact with each other at some point, causing a division of them into their aliquot parts.

I have endeavoured to ascertain by measurement the relative length of the vocal cords in the male and female larynx. The following table shows the results which I have obtained in several experiments:

	<i>Men past puberty.</i>						<i>Women past puberty.</i>			<i>Boy of 14 years.</i>
Length of the vocal cords at the greatest degree of tension	21	21	25	26	23	23	16	15	16	14·5
Length of the vocal cords in the state of repose	18	16	- -	21	19	- -	12	12	14	10·5
							<i>Male larynx.</i>		<i>Female larynx.</i>	
Mean length of the vocal cords in the state of repose							18 $\frac{1}{4}$		12 $\frac{2}{3}$	
Mean length of the vocal cords in the state of greatest tension							23 $\frac{1}{8}$		15 $\frac{2}{3}$	

The cyphers indicate the number of millimetres.* The relative length of the vocal cords in the male and in the female larynx would appear from these measurements to be as three to two, both in the extended and the unextended state. The degree to which the cords can be extended beyond their ordinary length is, in the male larynx, somewhat less than five millim.; in the female, three millim. The vocal cords alone, and not the whole length of the aperture of the glottis, extending posteriorly between the arytenoid cartilages, were measured. A small part of the vocal ligament extends farther back than the extreme point of the anterior process of the arytenoid cartilage, being attached to the

* [A millimetre is 0·03937, or about $\frac{1}{25}$ of an English inch.]

upper border of this process towards the anterior edge of the cartilage; this portion of the ligament was included in the measurements.*

If the air be drawn in through the glottis instead of forced out, the tension of the vocal cords remaining the same, no vocal sound is generally produced, but sometimes a deeper rustling sound was heard. (Compare the experiments on the tongues of caoutchouc at page 989.) Touching the outer part of the ligaments of the glottis, so as to stop the vibrations at that part, raises the pitch of the sounds, as in the case of caoutchouc tongues (see page 991).

Influence of the vocal tube.—The length of the tube prefixed to the vibrating tongues, which has so marked an influence in modifying the height of the notes produced by tongues of caoutchouc or even of arterial tissue, appears from my experiments to have, contrary to M. Magendie's opinion, founded on the analogy of the organ of voice with the reed-pipes of M. Grenié, no perceptible effect on the pitch of the notes yielded by the human larynx. In many cases the variation of the length of the prefixed tube seemed to have no influence at all on the note produced; in other instances the elongation of the tube lowered the note a semitone, very rarely an entire tone, when the force of the blast was perfectly uniform. I am inclined, therefore, to deny any power of modifying the height of the notes to the slight variation of length which the trachea can undergo.

The superaddition of a tube in front of the vocal cords, which were already furnished with a prefixed tube or "porte-vent" of given length,†

* Admeasurements of the vocal cords of the larynx in the tense and lax condition, in bass, tenor, contr'alto, and soprano singers, and also in eunuchs, after death, would be of great interest in a physiological point of view; but the same parts should be measured in other individuals at the same time, that the grounds of the comparison may be the same: for if the vocal cords be measured from their anterior extremity only, as far as the point of the anterior process of the arytenoid cartilage, the length indicated will be less than when they are measured in the manner above described.

† The performance of these experiments is attended with great difficulty. In the first place, it is not easy to fix a tube to the larynx in front of the vocal ligaments; and, when this is done, it is difficult to give the vocal cords a determinate degree of tension. These objects are attained in the following manner:—The posterior extremities of the vocal cords are tied together, by means of a ligature, close to the anterior or vocal processes of the arytenoid cartilages, the ends of the ligature being brought out backwards over the membrane between those cartilages. The epiglottis, aryteno-epiglottic ligaments, the capitula laryngis of Santorini, and the membrane and muscles uniting the arytenoid cartilages, are left to facilitate the attachment of the tube; and, for the same purpose, the upper border of the thyroid cartilage is cut away. A short tube, six or eight lines in diameter, being fixed in front of the larynx, other portions of the same size can be added to it as required. The larynx being fixed, and the arytenoid cartilages approximated by a ligature from behind, any degree of tension required can be given to the vocal cords by means of the ligature by which they are bound together at their posterior extremity. The opening by which this ligature is brought out of the cavity of the larynx at its posterior wall is closed during the production of the sounds produced by blowing.

had likewise either no influence on the pitch of the notes, or caused the difference of only a semitone, or very rarely a tone.

I have instituted many experiments, with the view of ascertaining the cause of this want of agreement between the natural and artificial larynx.* The most probable explanation appears to me to be, that in the human larynx the vocal cords, at a certain degree of tension, are for the most part alone engaged in sonorous vibrations, the membrane which connects them with the walls of the larynx not being made tense; while in the artificial larynx, constructed with laminæ of caoutchouc or arterial tissue, the vibrations are effected not merely by their longitudinal extension at their free border, but also by the more lax portion, as is evident from the effect of slightly touching them at their outer part so as to damp its vibrations (see page 991). On account of the greater breadth of these elastic membranes, and from the connection of their tense with their unextended portion, they are capable of many more modifications of vibrations and sounds required by the varying length of the prefixed or superadded tubes (the "porte-vent" and "pipe") than is the glottis, in which the vibrations are principally confined to the vocal cords themselves.

I imagined that the extensile nature of the trachea might have some share in diminishing the influence of the length of the superadded tubes in front of the glottis on the height of the notes given out by it; but, on substituting for the trachea a wooden tube, I found no difference in the result. It is possible, however, that the extensile property of the membrane connecting the different cartilages of the larynx, while the walls of the artificial larynx with caoutchouc tongues are quite solid and inextensile, may be in some measure the cause of this peculiarity of the natural larynx.

In my experiments on the influence of tubes of different length on the height of the note produced by the vibrations of the vocal cords, it sometimes appeared that the note was not so perfect when the prefixed tube had a certain length as when its length was different, owing to the column of air not being of such length as to accommodate itself to the vibrating tongues. Mr. Wheatstone† had previously made the same remark with reference to other reed-instruments, and Mr. Bishop attributes great importance to the reciprocal adaptation of the columns of air above and below the vocal cords to each other during life. The circumstance to which I have alluded occurred, however, but very few

* This want of agreement is not however absolute; for sometimes, particularly when the sounds are produced with difficulty, the bands of caoutchouc being too tense or too lax, these artificial vocal cords yielded sounds which were not at all, or only in a very inconsiderable degree, lowered in pitch by the elongation either of the tube placed below the vibrating tongues or of that prefixed to them (see Appendix to page 994.)

† Mayo's Physiology, Ed. 4th, p. 373.

times in my experiments; I cannot, consequently, ascribe the great importance to this accommodation of the columns of air in the human organ of voice which Mr. Bishop does. On the contrary, it is evident that the shortening and elongation of the trachea, and the shortening and elongation of the vocal tube in front of the glottis, by the elevation or depression of the larynx, can have but very little influence on the acuteness of the vocal sounds. At most, we can merely admit that the elongation of the vocal tube in front of the glottis by the descent of the larynx, *cæteris paribus*, facilitates the formation of the deep notes, and the shortening of the tube by the ascent of the larynx that of the high notes; thus much is, in fact, confirmed by what takes place in the formation of high and low notes during life.

The partly membranous nature of the trachea has no perceptible influence on the sounds produced by the vocal cords; the note produced by blowing through the trachea was the same as when a wooden tube of the same diameter was used. In this respect reed-instruments with membranous tongues differ remarkably from flute-pipes with merely a vibrating column of air. In the latter instruments the reciprocal vibrations of the membranous walls of the tube influence so much the primary vibrations of the column of air, that, according to the observation of M. Savart,* who discovered this circumstance, a pipe of moist thin paper walls will lower the note an entire octave below that which a tube of solid parietes of the same length would yield. In very short cubic pipes the difference may be as much as two octaves (see page 981). I formed a tube, $7\frac{1}{2}$ inches in length, partly of human trachea, which measured 3 inches, and in the rest of its extent ($4\frac{1}{2}$ inches) of a wooden pipe. The note produced by blowing through this tube upon a vibrating tongue of caoutchouc at its lower extremity was the same as when the tube used was of equal length but of solid materials. The contact of the hand with the membranous part of the trachea had no perceptible influence on the note.†

* Froriep's Not. 332, p. 21.

† [Mr. Wheatstone had observed, that columns of air reciprocate the sonorous vibrations of other columns of air, or of vibrating bars or reeds in their neighbourhood, rendering the sound much louder, when their length is such that they would alone yield the same note; but that, if not thus in unison, they will not reciprocate the vibrations of other bodies.—(Quarterly Journal of Science, vol. iii.) He applied this law to the human organ of voice, supposing that the trachea undergoes changes in length in accordance with the notes produced by the vibrating vocal cords; its length being diminished as the sounds become sharper. But since the larynx ascends during the production of high notes, it would appear that the trachea is lengthened when it ought to be shortened: Mr. Bishop states, however, that the trachea is not really lengthened by this movement of the larynx; he finds that it is raised out of the thorax nearly to the same extent as the larynx is elevated; he therefore concludes, that an absolute shortening of the entire vocal tube, including the trachea and the

The circumstance of the vocal tube in front of the vocal cords being double, consisting of the oral and nasal canals, seems to have no other effect on the height of the notes than a simple tube ; but it causes their character to be altered by the resonance. I attached to the short anterior tube of an artificial larynx with caoutchouc tongues a bifurcated tube ; the result was no raising of the notes, but they were rendered more sonorous.

The *epiglottis*, by being pressed down so as to cover the superior cavity of the larynx, serves to render the notes deeper in tone, and at the same time somewhat duller, just as covering the end of a short tube placed in front of caoutchouc tongues lowers the tone (see page 994). In uttering very deep notes during life, we evidently employ the epiglottis in this way ; at least, such seems to be the object of the retraction and depression of the tongue while we press down the head in front, in endeavouring to produce very deep notes. In no other respect does the epiglottis appear to have any effect in modifying the vocal sounds. Direct experiments which I have performed do not confirm the opinion of MM. Biot and Magendie, that the epiglottis has the same office as the vibrating plate which M. Grenié, an organ-builder, placed in front of the metallic tongue of a reed-instrument with a view of facilitating the elevation of the notes by a more forcible current of air. An epiglottis placed in the pipe in front of the vibrating tongues of an artificial larynx in about the same situation as in the natural organ, and with such a disposition that it could vibrate freely, had no effect on the height of the note ; if the epiglottis was so placed as to act as a fixed impediment to the current of air, the result was the same as when the tube in front of the vibrating tongues was narrowed in any other way. By gradually increasing the force of the blast, the height of the note can, *cæteris paribus*, be raised the extent of a "fifth," whether

cavities above the glottis, is produced by the elevation of the larynx towards the base of the skull. But the variation in the length of the tube being insufficient to render it capable of adjusting itself to the whole range of vocal tones, Mr. Wheatstone (Mayo's Physiology, Ed. 4th, p. 373,) and Mr. Bishop suppose that the defect is supplied by the varying tension of the walls of the trachea ; on the principle determined by M. Savart, that a tube of constant length may yield an extensive range of sounds if its elastic parietes are made to vary in tension. The diminished diameter of the trachea during the ascent of the larynx would, Mr. Bishop remarks, favour the production of higher notes. A still further influence on the voice is attributed to the trachea by Mr. Wheatstone. He has observed, that a column of air may not only vibrate by reciprocation with another body whose vibrations are isochronous with its own, but also when the number of its own vibrations are any multiple of those of the sounding body. Such would be the vibrations of the column of air in the trachea divided into harmonic lengths, with relation to the vibrations of the vocal cords. The falsetto notes, he suggests, may be the result of the vibrations of the harmonic subdivisions of the column of air in the trachea. Mr. Bishop adopts this view.]

the epiglottis be present or not. The epiglottis can be felt, by the finger passed in at the side of the mouth, to maintain the same position during the utterance of musical notes, whether they be of the falsetto character or those of the natural voice.

The *arches of the palate and the uvula* become contracted during the formation of the higher notes, as was first observed by Fabricius ab Aquapendente, and more recently by Mayer, Bennati, and Dzondi. But the contraction of the isthmus of the fauces is the same for a note of given height, whether it be falsetto or not; and in either case the arches of the palate may be touched with the finger, without the note being altered. This completely refutes the opinion of Bennati, that the falsetto tone is wholly or in part due to the action of the palatine arches.

The approximation of the palatine arches, and retraction of the uvula, in the production of the higher notes, seems to be merely the result of involuntary associate nervous action, caused by the voluntarily increased exertion of the muscles of the larynx. If the palatine arches contribute at all to the production of the higher notes of the natural voice and the falsetto register, it can only be by their increased tension strengthening the resonance.

According to the theory of reed-instruments, narrowing of the *upper part of the larynx* immediately in front of the vibrating tongues or vocal cords ought to raise the notes in some degree: but this cannot be proved experimentally; for, in a larynx removed from the body, the upper part of the cavity cannot be compressed without, in some measure, acting on the vocal cords. Simple narrowing has no perceptible influence. The office of the *ventricles of the larynx* is evidently, as M. Malgaigne, Sir C. Bell, and others have remarked, merely to afford a free space for the vibrations of the lips of the glottis. M. Malgaigne compares them to the cavity at the commencement of the mouth-piece of trumpets, which allows the free vibration of the lips.

C. *Theories of the voice.*

The general conclusion which we must draw from the results of the experiments on the artificial larynx with membranous tongues, as well as from those afforded by the experiments on the natural larynx removed from the body, which, in all essential points, agree with the former, is that *the human organ of voice is a reed-instrument with a double membranous tongue*. This opinion has been previously held by several cultivators of natural philosophy, as MM. Biot, Cagniard la Tour, and Muncke; by writers on the theory of music, as Gottfr. Weber; and by some physiologists, as MM. Magendie, Malgaigne, and others.

The experiments of Ferrein on the sounds to be obtained from the larynx in the dead body, by which he showed that the note varied according to the length and tension of the vocal cords, have, as early as the year 1741,* afforded a sound basis for this theory. Even M. Savart,† who denied the analogy of the larynx with a reed-instrument, admitted that when air is blown into the trachea after the removal of the upper part of the larynx, as low as the inferior ligaments or vocal cords, notes can be produced in the same way as by means of vibrating tongues: it is true, he stated that the sounds thus produced were different from those of the human voice; to me, however, they appear, when the experiment is performed as I have directed, to differ in no essential respect from the vocal sounds: I obtain, by the methods I have described, notes of the natural scale, and falsetto notes with all their characteristic tones; any difference between them and the vocal sounds of the living larynx may be attributed to the influence of the vocal tube in front of the larynx.

According to M. Savart, the air in the ventricles of the larynx between the superior or false, and inferior or true ligaments, is really the source of the sound; the organ of voice being compared by this philosopher to the bird-call or hunter's whistle, described at page 980. The elastic structure of the inferior ligaments of the larynx or vocal cords, and the contrivances adopted for rendering them tense, characterise the larynx, however, too evidently as an instrument with vibrating tongues, to permit us to attribute much importance to M. Savart's objection respecting the difference of tone; and, moreover, the notes may be modified by varying the tension of the vocal cords, as well when the ventricles of the larynx and superior ligaments are preserved as when they are removed, leaving merely the true vocal cords. The theory of M. Savart is rendered quite untenable by the fact of the superior ligaments of the glottis being entirely absent in some mammalia, namely, in the ruminantia.

The apparatus in front of the true vocal cords may probably, like the pipe of reed-instruments, have some influence in modifying the vocal sounds, particularly by undergoing contraction in the upper cavity of the larynx, at which part changes can be produced that cannot be imitated in artificial reed-instruments; changes in the length of the tube in front of the glottis are less influential. The principal cause of the vocal sounds, however, is still the vibration of the vocal cords.

Fechner‡ objects to the theory of the organ of voice being a reed-instrument, that in that case no sound could be produced while the glottis is open, since the sound emitted by reeds is supposed to be

* Mém. de l'Acad. d. Sc.

† Magendie's Journal de Physiol. t. v.

‡ In his translation of Biot's Précis de Physique.

owing to the periodic interruption of the current of air by the alternate opening and closing of the passage; whereas the vocal cords can vibrate and produce sounds without the glottis being periodically closed. We have, however, shown that the theory of the sounds emitted by reed-instruments, on which this objection of Fechner is based, is not so accurate as is generally supposed; for, by merely directing a current of air across the edge of delicate tongues without surrounding frame, the same notes with the same "timbre" may be produced as by blowing through an opening closed by a tongue acting as a valve: again, the current of air which throws the tongue of a reed-instrument, whether metal or membranous, into sonorous vibrations, may be so strong as to prevent its returning to close the opening periodically; and lastly, notes may often be elicited from an artificial larynx with caoutchouc tongues when a space of considerable width intervenes between the lips of the tongues.

The vocal cords were likened by Ferrein to vibrating strings, and to a certain extent correctly; but the comparison is in other points inaccurate. Ferrein's experiments, by which he demonstrated the resemblance of the vocal cords to vibrating strings, are among the best that have ever been instituted. He showed that the vocal cords sound, according to analogous laws with those of strings which are thrown into sonorous vibrations by currents of air, and that the notes produced are in no respect altered by difference in width of the aperture of the glottis. From half the length of the vocal cords he obtained the octave of the fundamental note; from two-thirds, the fifth. Lastly, he found that a change in the length of the vocal cords to the extent of from two to three lines was sufficient to produce all the notes of various pitch (the change in tension here supplying what is effected by change in the length of the cords when the tension remains the same). M. Bertin attempted to controvert these experiments; but they were confirmed by Montagnat, Runge, and Nollet.* My experiments on caoutchouc tongues, already detailed, (page 988,) afforded completely parallel results; and the experiments on the effect of graduated extension on the notes of the vocal cords also prove that their vibrations obey the general laws of vibrating strings. I cannot assent to M. Biot's remark, when he says,† "What is there in the larynx that resembles a vibrating string? where is the space for such a string of sufficient length to yield the lower notes of the voice? How could sounds of the compass which the human voice presents, be produced by a string which the larynx would contain? The simplest prin-

* See Haller's *Element. Physiol.* t. iii. libr. ix. § 8, 9, and 10.

† *Précis de Physique*, t. i. p. 458.—*Lehrbuch der Experimental-phys.* ii. p. 143.

ciples of acoustics are sufficient to refute this strange notion." M. Biot's objection can be easily controverted. A string, however much shortened, would still be able to yield deep notes, if, at the proper degree of relaxation, it retained the necessary elasticity for vibration. The elastic membranes and the laminae of caoutchouc retain this elasticity when greatly relaxed. Small bands of caoutchouc indeed, if made tense, give out clear sounds when struck, although these sounds are not of long duration as when produced by long strings. The continuous influence of the current of air in blowing renders these sounds continuous; and converts a lamella, which vibrates as a string when simply struck, into a tongue. In this respect, therefore, the vocal cords agree perfectly with vibrating strings, and the only difference in their action arises from the body by which their vibrations are excited. Thus far Ferrein's comparison of the vocal cords to strings is completely accurate.

In one respect, however, the vocal cords differ from strings; and this point of distinction is important enough to give to them, with other membranous tongues, a special place among musical instruments. When strings are more strongly struck, deeper notes are produced; the note given out by a membranous tongue is, on the contrary, raised by a stronger blast the extent of one, two, or more semitones; and if the tongues be of moist nature, as are the vocal cords and bands of arterial tissue, even many semitones. The sound emitted by the metal tongue of a child's trumpet also always rises, according to my observation, the extent of an octave and a half without intervals, when blown with increased force; and the reason that this is not the case with other metal tongues is, that they are too strong to be affected by the current of air. The note emitted by a tongue depends, therefore, not only on the tongue itself, but also on the air giving the impulse. A string, on the contrary, being once struck, its vibrations undergo no further modification by the continued impulse; the vibrations, once excited, are regulated only by the length and tension of the string.—(See Appendix, p. 11. —*Theory of the action of Tongues.*)

There are several physiologists, and among them Dodart and Liscovius, who ascribe the modulation of the voice to the varying size of the fissure between the lips of the glottis, and to the vibration of the air produced at that part. Dodart* was acquainted with the influence of the tension of the vocal cords upon the notes produced; but he supposed that the variation of the tension of these cords acted by altering the size of the opening through which the air, vibrating in its passage, is transmitted. The difference of $\frac{1}{54}$ of a fibre of silk, or $\frac{1}{384}$ of a hair, in the size of the rima glottidis, was sufficient, he supposed, to produce a dif-

* Mém. de l'Acad. d. Sc. 1700.

ferent note. This is quite erroneous; for even a considerable difference in the width of the rima glottidis, if the tension of the vocal cords remain the same, has no effect on the pitch of the notes produced. Liscovius* supposes that the air driven with some force and rapidity through the opening of the glottis experiences such compression and impulses that its smallest particles are moved to and fro, as in other cases, where air is propelled through any narrow orifice; and that the larger the opening of the glottis is, the deeper will be the note produced, in consequence of the undulations of the air being then larger, and therefore slower.

The arguments which Liscovius adduces in opposition to the opinion that the vocal cords are the source of the sound are,—First, That the vocal cords are stretched during the production of deep notes, and relaxed while high notes are being uttered; for the glottis, he says, is dilated, and the vocal cords are separated from each other, during the production of deep notes. The dilatation of an opening is necessarily attended with extension of its borders, if their continuity be perfect; hence, he says, dilatation of the glottis cannot take place without its lips becoming extended; and for deep notes the vocal cords must be tense, for high notes relaxed. This is evidently an error. When a certain degree of tension has been given to the vocal cords by the contrivance described at page 1008, the width of the aperture of the glottis may be varied at will, without the tension of the cords being altered. The aperture of the glottis can, in fact, be either wide or narrow, whether the cords be tense or relaxed. Moreover, the fact that the posterior part of the aperture of the glottis, that part which lies between the arytenoid cartilages, may be either closed or open (see page 1009), without the pitch of the notes being thereby modified, proves that the air cannot be the primary source of the sound; otherwise the notes would be much lower when the glottis is open in its entire length, than when that part merely is open, which is included between the vocal cords themselves. Next, Liscovius remarks that dry strings only can be elastic, and that the vocal cords are always moist. The string, however, is only one kind of cord-like body made elastic by tension; and this kind loses its elasticity when made moist. The elastic tissue of the human body, on the contrary, is elastic only when it is moist, and loses its elasticity as it becomes dry. These are differences which do not alter the fixed laws regulating the action of cord-like bodies made elastic by tension. We have already refuted the objection that the vocal cords cannot possibly give rise to so many and such deep notes. In comparing the vocal cords with strings, the attention has been confined too much to the properties of one kind of cord-shaped body elastic by tension, and hence have arisen erroneous views. If, for

* *Theorie der Stimme.* Leipzig, 1814.

the strings of gut, more elastic cords, or bands of caoutchouc or animal elastic tissue, be substituted, much that belongs only to the strings, and is not essentially the property of elastic tense cords, is got rid of. Liscovius remarks, that no string can receive sufficient impulse from a mere current of air to produce sounds of any intensity. But bands of caoutchouc, or of moist animal elastic tissue, when a fine current of air from a small tube is directed free upon them, emit very loud sounds. To the assertion of Liscovius that the tension and relaxation of the ligaments of the glottis have no influence on the pitch of the notes, except inasmuch as the aperture of the glottis is thereby dilated or contracted, I must oppose the constant result of my experiments,—namely, that notes to the extent of two octaves may be produced by the mere variation of the tension of the vocal cords, the width of the rima glottidis remaining the same.

Liscovius observed that if, while air was blown into the glottis, one of the vocal cords was very tense and the other very lax, two notes were not produced, but one only, the height of which was proportionate to the width of the aperture between the vocal cords. The first part of this observation is perfectly correct. In this respect the vocal cords exactly resemble the tongues of caoutchouc, of which, as we have seen, only one gives sound, while the other acts as a fixed boundary of the opening, if their degree of tension be unequal. On some rare occasions, however, each caoutchouc tongue gives utterance to its fundamental note, and the same is the case with the vocal cords.

Liscovius found that when he touched the vocal cords with the finger, without affecting the size of the aperture of the glottis, the pitch of the note remained unaltered; while, if the vocal cords were subject to the laws of vibrating strings, the note ought to have been raised. According to my experiments on laminæ of caoutchouc, as well as my observations on the vocal cords, touching them so as to damp their vibrations modifies very much the height of the note they yield, even though the size of the aperture remain the same.

It is supposed that mere diminution of the size of the glottis, without any change in the tension of the vocal cords, will render the pitch of the note higher, and that mere dilatation of the opening will render them lower; the pitch of the notes being regulated, however, not by the mere width of the aperture, but by its whole area,—the length and breadth together. My experiments have taught me that low notes may be obtained from a much shortened rima glottidis, provided the vocal cords are quite relaxed; and that, though the notes rise in proportion as the glottis is shortened from before backwards, yet this only takes place when the tension of the cords remains the same. The width of the aperture of the glottis has no essential influence upon the pitch of the notes, except inasmuch as it is difficult to elicit sounds from the larynx by blowing through the

trachea when the aperture of the glottis is wide; the sound is then not only devoid of musical tone, but the note can be raised by increased force of the blast a trifling degree only above the fundamental note; while, when the aperture of the glottis is narrow, it may be raised by this means a succession of semitones up to the "fifth," or beyond it.

The influence of increasing the force of the blast in raising the pitch of the notes was correctly observed by Liscovius and Lehfeldt. A point of especial importance in reference to the theory of the production of the notes of the natural register and the falsetto notes,—namely, that for the former the entire vocal cord vibrates, and for the latter only its border, as well as the fact that the falsetto note is, *cæteris paribus*, higher,—was first discovered by Lehfeldt.*

D. *Of singing.*

There are three different kinds of sequence of the notes which the organ of voice is capable of producing. The first is the monotonous, in which the notes succeeding each other have all nearly the same pitch, as in ordinary speaking; the variety of the sounds of speech being owing to articulation in the mouth; in speaking, however, occasional syllables generally receive a higher intonation for the sake of accent. In poetry there is rhythm in addition to the accent, but the modulation of music is wanting. The second mode of sequence is the successive transition from high to low notes, and *vice versâ*, without intervals; such as is heard in the sounds, which, as expressions of passion, accompany crying in men, and also in the howling and whining of dogs. This succession of dissonant sounds, in which the musical intervals are not observed, often occurs in nature, as in the howling of the wind; and may be produced on instruments,—for instance, by diminishing or increasing the tension of a string while it is being sounded, or by blowing with gradually increased force into a short pipe closed at one extremity. A membranous tongue is capable of the same succession of notes, and the same is the case with the vocal cords. The dissonant succession of rising and falling notes in howling must be produced partly by increase and diminution of the force of the current of breath, and partly by gradual alteration of the degree of tension of the vocal cords. The third mode of sequence of the vocal sounds is the musical, in which each

* Of previous writers, Ferrein, Liscovius, and Lehfeldt, have contributed most to the elucidation of the theory of the voice. A very good account of the opinion of the older writers, with original reflections, is contained in Lehfeldt's dissertation, "*De vocis formatione.*" Berol. 1835. A complete review of later theories and observations will be found in Heusinger's edition of Magendie's *Physiology*.

sound has the requisite number of vibrations, and the number of vibrations in the successive sounds have that relative proportion which characterises the notes of the musical scale. Music has a rhythm in common with poetry.

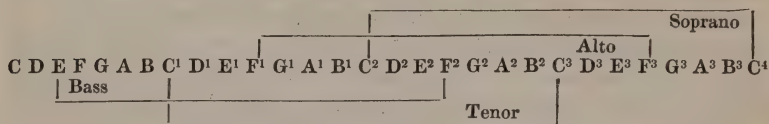
1. *Compass of the voice.*—The compass of the voice in different individuals comprehends one, two, or three octaves; in singers,—that is, in persons capable of singing,—it extends to two or three octaves. But the male and female voices commence and end at different points of the scale. If we commence the scale at the C of the eight-foot organ-pipe

, the male bass voice will take its beginning from the first E,

the barytone at A, the tenor at C¹; and these male voices will reach, the bass to A¹, or higher, the barytone to F², and the tenor to C³. The female voice is as deep as the male only in masculine women. The voices of women, boys, and eunuchs begin between F¹ for the alto, and C² for the soprano, and reach as high as F³ for the alto voice, or A³ for the mezzo-soprano, or C⁴ for the soprano, at the furthest as high as F⁴. The lowest note of the female voice is therefore about an octave higher than the lowest of the male voice; the highest note of the female voice about an octave higher than the highest of the male. The first four notes of all voices are generally weak. The compass of the male and female voices taken together, or the entire scale of the human voice,

includes four octaves, — namely, from E  to E⁴ .

For the convenience of readily comparing the extent of the different voices, we subjoin a table of the whole scale of the human voice, showing the mean compass of its different varieties.



Fischer, the father of the singers who afterwards became celebrated, could reach to the F of the octave below the above scale,—namely

; the youngest of the female singers, named Sessi, had a

compass of voice of three octaves and three notes,—namely, from C¹ to

F⁴.* Zelter's voice included three; Catalani's, three and a half octaves.†

2. *Varieties of voice in different individuals.* The principle difference between the male and the female voice is in their pitch; but they are also distinguished by their tone,—the male voice is not so soft. But the voice presents other varieties besides the male and female; there are two kinds of male voice, the bass and tenor, and two kinds of female voice, the contr'alto and soprano, all differing from each other in tone. The bass voice usually reaches lower than the tenor, and its strength lies in the low notes; while the tenor voice extends higher than the bass. The contr'alto voice has generally lower notes than the soprano, and is strongest in the lower notes of the female voice; while the soprano voice reaches higher in the scale. But this is not the essential distinction between the different voices; for bass singers can sometimes go very high, and the contr'alto frequently sings the high notes like soprano singers. The essential difference between the bass and tenor voices, and between the contr'alto and soprano, consists in their tone or "timbre," which distinguishes them even when they are singing the same note. The qualities of the barytone and mezzo-soprano voice are less marked; the barytone being intermediate between the bass and tenor, the mezzo-soprano between the contr'alto and soprano. They have also a middle position as to pitch in the scale of the male and female voices.

The different pitch of the male and the female voice depends on the different length of the vocal cords in the two sexes; their relative length in men and women being as three to two (see page 1018). The difference of the two voices in tone or "timbre" is owing to the different nature and form of the resounding walls, which in the male larynx are much more extensive, and form a much more acute angle anteriorly. The different qualities of the tenor and bass, and of the alto and soprano voices, probably depend on some peculiarities of the ligaments and the membranous and cartilaginous parieties of the laryngeal cavity, which are not at present understood, but which might be determined by the examination of the larynx in different tenor, bass, soprano, and contr'alto singers after death. We may form an idea of the cause of these differences of timbre from recollecting that musical instruments made of different materials, as metallic and gut strings, metallic, wooden, and membranous tongues, metallic, wooden, and paper pipes or flutes, may be tuned to the same note, but that each will give it with a peculiar tone or timbre.

The larynx of boys resembles the female larynx; their vocal cords before puberty have not two-thirds the length which they acquire at that period. The angle of the thyroid cartilage is as little prominent

* Muncke in Gehler's Physik. Wörterbuch, t. viii. p. 386.

† Rudolphi, Physiologie.

as in the female larynx. Boys' voices are alto and soprano; but, after the larynx has undergone the change produced during the period of development at puberty (between the fourteenth and the fifteenth year), they become immediately bass or tenor. While the change of form is taking place, the voice is imperfect, frequently hoarse and crowing, and is unfitted for singing until the new tones are brought under command by practice. In eunuchs, who have been deprived of the testes before puberty, the voice does not undergo the ordinary change. The contr'-alto and soprano voices of boys and eunuchs resemble in pitch those of women; but differ somewhat from them in timbre, and are louder. Liscovius remarks that the eunuch's voice differs in tone from the boy's, and attributes this difference to the circumstances of the resounding walls of the cavities of the mouth and nares becoming as extensive in the eunuch as in other men, though the larynx remains in the condition of youth. But those cavities are also spacious in women; and the greater firmness of the cartilages and ligaments of the larynx in the eunuch than in the boy may have a greater influence.

3. *Varieties of voice in one and the same individual.*—*The natural and falsetto voices.*—Most persons, particularly men, besides that their voice belongs more or less to one of the varieties already described, have the power, if at all capable of singing, of modulating through a double series of notes of different character. These are the notes of the natural voice, or chest-notes (note di pettò), and the falsetto notes (note di testa). The natural voice is fuller, and excites a distinct sensation of much stronger vibration and resonance, than the falsetto voice, which has more a humming character. The deeper notes of the male voice can be produced only with the natural voice,—the highest with the falsetto only; the notes of middle pitch can be produced either with the natural or falsetto voice; the two registers of the voice are therefore not limited in such manner that one ends when the other begins, but they run in part side by side. The tenor voice generally follows the falsetto register, from A^2 of the scale given at page 1030, while the notes below A^2 can be uttered either with the natural or falsetto character. The bass voice becomes falsetto lower in the scale than the tenor. The female voice seldom presents a sufficiently marked distinction between the natural and falsetto registers.

The mode of production of the natural register of vocal sounds and the falsetto register has been already explained (see page 1013). Since the note of the natural register is much deeper than the falsetto note produced by vocal cords in the same state of relaxation, and by blowing with as much as possible the same force; and since a note of the natural register can be raised to the same pitch as the falsetto note only by compressing the cavity of the larynx below the vocal cords, or by increasing the force of the current of breath; we may understand why, in passing

from the natural to the falsetto register, it is often difficult to hit upon the right falsetto note.

4. *Differences of the voice as to tone.*—Each individual has a peculiar tone of voice dependent on the form of the air-passages and of their lining membranes, and on their resonance: hence, many persons, by altering the form of their vocal organs, can imitate the various tones of voice of other individuals. The nasal “*timbre*” is a peculiar quality of voice dependent on a similar cause. M. Biot supposes that the ordinary character of the voice is due to the soft palate applying itself to the posterior nares and closing them, so that the air can escape only through the mouth. But I cannot subscribe to this opinion; for ordinarily, while the voice has its natural character, the posterior nares are open, and the voice resounds through both the oral and the nasal tube simultaneously. The nasal tone may be given to the voice in two ways: 1. When the external openings of the nares are closed the voice may retain its natural sound, or it may become nasal: in the former case the arches of the fauces remain open; in the latter they approach each other, and the larynx ascends much higher than when the voice has its natural character. Obstruction of the nostrils by mucus has the same effect as closing the anterior openings of the nares; but neither the one nor the other can alone give the nasal tone to the voice. When the nasal tone is produced in this first way, the cavity of the nostrils becomes a separate resounding chamber. 2. The nasal twang may also be given when the nostrils are open, the mouth being either open or closed. In this case likewise the larynx ascends considerably; the arches of the fauces contract; the dorsum of the tongue is approximated to the palate, or brought into contact with it; and the air merely passes between the narrowed arches of the fauces, and receives the resonance of the nasal cavities without that of the cavity of the mouth.

The voice of old people is deficient in tone, is unsteady, and more restricted in extent: the first defect is owing to the ossification of the cartilages of the larynx and altered condition of the vocal cords; the want of steadiness arises from the loss of nervous command over the muscles; the result of which is here, as in other parts, a tremulous motion. These two causes combined render the voice of old people void of tone, unsteady, bleating, and weak.

5. *Strength of the voice.*—This depends partly on the degree of capability of vibration of the vocal cords; and partly on the fitness of the membranes and cartilages of the larynx, of the parietes of the thorax, lungs, and cavities of the mouth, nostrils, and communicating sinuses, for resonance. The capability of vibration of the vocal cords is diminished or destroyed by inflammation and suppuration of the mucous membrane of the larynx, by profuse secretion of mucus, by œdema glottidis, &c. The resonance of the pulmonary membrane is diminished,

and the voice consequently rendered weaker, by phthysical disease. The strength of the male voice is also in part attributable to the greater capacity of the chest. In many genera of apes there are other accessory resounding membranous sacs communicating with the throat, or indeed saclike expansions of the thyroid cartilages and os hyoides, as in the howling apes, *Mycetes*.

6. *Increase and diminution of the intensity of the vocal sounds.*—The intensity or loudness of a given note emitted by the larynx cannot be rendered greater by merely increasing the force of the current of air through the glottis; for increase of the force of the current of air, *cæteris paribus*, raises the pitch both of the natural and the falsetto notes. Increased strength of the blast has the same effect on the notes produced by some musical instruments, namely, flute-pipes and reed-instruments with delicate metal tongues or membranous tongues (see pages 991 and 992); strong metal tongues, on the contrary, emit a lower note when the force of the current of air is increased. This defect, which prevents the harmony from remaining perfect when notes are swelled or sounded more faintly, can be remedied, according to the observation of W. Weber, in the case of the stronger metallic tongues, by combining with them a tube accurately measured so as to be in unison with the fundamental note of the tongue; the tongue lowering the note while the column of air in the tube raises it, a compensation is established which enables the player to increase or diminish the intensity of the note without altering its pitch. This principle of compensation cannot, however, be applied in the case of the membranous tongues, since their notes are raised like those of the column of air in pipes by increased force of blast; we cannot, therefore, expect to find a relation of compensation between the vocal cords and column of air in the vocal tube in the human organ of voice: moreover, a very different length of tube would have been required for different notes, and the vocal tube can be altered in length at most but an inch, by the ascent and descent of the larynx.

Since the human organ of voice possesses the power of increasing the intensity of a note from the faintest “piano” to “fortissimo” without its pitch being altered, there must be some other means of compensating the tendency of the vocal cords to emit a higher note when the force of the current of air is increased. This means evidently consists in modifying the tension of the vocal cords. When a note is rendered more intense, the vocal cords must be relaxed by remission of the muscular action in proportion as the force of the current of the breath through the glottis is increased. When a note is rendered fainter, the reverse of this must occur. The analogy of the reed-instruments constructed with membranous tongues, and the experiments on the production of the higher notes of the musical scale, (page 1014,) teach us also

that the contraction of the cavity of the larynx immediately below the glottis by the action of the thyro-arytenoid muscles may assist in compensating for the effect of diminishing the force of the current of air in passing from "forte" to "piano," for contraction of the cavity at that part raises the pitch of the note; and, if the note be raised in pitch by the increased force of the current of air, the dilatation of the same part of the larynx may lower it.

For such actions of compensation an accurate balancing of the opposed actions is necessary; and hence we can understand why the raising and lowering the voice without altering the musical pitch of the note is so difficult, even for practised singers, and cannot be at all effected by the unpractised without dissonance being produced in one way or other.

7. *Perfectness of the notes.*—The dissonance of the voice after long singing may easily be accounted for in part by the slight changes which the vocal cords have undergone in consequence of repeated tension; and in a greater degree by the fatigue of the muscles, which at length cease to obey the will perfectly, and execute inappropriate movements. An habitual dissonance of the voice, or inability to sing in tune, depends partly on defect of the sense of hearing, and partly on the difficulty of observing the uniform "temperament" of our musical scales. Temperament is usually already obtained in musical instruments by tuning; the singer must attend to it at each note.

Man, like the singing-bird, learns unconsciously the different internal changes in the state of the larynx, and the different muscular actions necessary for each note. Sounds accidentally uttered, and the muscular actions which accompanied them, become associated in the sensorium, and afterwards readily excite each other when a melody is to be imitated. When singing is learnt methodically, the signs of the different notes are also associated with them, and with the muscular motions producing them. In addition to all this, however, a good ear is necessary; without which, a voice of good quality and great compass may be useless in singing.

We must conclude our observations on the human voice with some remarks on the artificial construction of a vocal organ. No musical instrument can be in all respects compared to the organ of voice; for even the organs and pianos, of which the compass is so great, are defective in other respects. Some musical instruments, as the simple flute-pipes, are not susceptible of an increase of the intensity of the notes from piano to forte; in others the notes cannot be prolonged, namely, in all those instruments in which the sounds are produced by striking strings. The organ has two registers of notes,—those of the flute-pipes and the reed-pipes; and in this respect it resembles the human voice, which has the natural register and the falsetto: but no instrument combines like the

human organ of voice all these advantages. Although the organ of voice belongs to the class of reed-instruments; and though these reeds, when combined with a system of compensating pipes, are (with the violin) the most perfect of all instruments; yet still the vocal organ is more perfect in being capable of giving with one tube all the notes and all the possible variations of the scale, while in the most complete instrument constructed of reed-pipes each note requires a special pipe. The artificial construction of a vocal organ would, in some measure, be attained, if with a reed-pipe an apparatus, of not too difficult management, for regulating the tension of elastic tongues in the reed, could be combined; but the tones of such an instrument, in which dry elastic bands only could be permanently used, would not resemble the soft full tones given out by the moist, animal, elastic tissue, and there would always be great difficulty in managing such an instrument.

2. *Of musical sounds formed in the mouth.*

We do not speak here of all the noises which may be produced in the mouth, but only of those which have a musical quality or tone. Both at the anterior and at the posterior part of the oral cavity musical sounds may be produced on the principle of the sounds of reed-instruments; such are the snoring and other sounds given out by the arches of the fauces in vibrating, and the sounds produced by pressing air between the lips which are thrown into distinct vibrations; the notes thus produced being higher in pitch, the greater the tension of the lips.

Another kind of musical sound produced in the mouth is "*whistling*,"* in which the air is the source of the sound. It is easy to convince one's-self that the sound in whistling is not owing to vibration of the lips; for they may be touched, covered, or even a disk of cork with a central hole held between them, as Cagniard la Tour showed, and yet the same sounds will be produced. Cagniard la Tour's theory of the cause of the sound appears to me to be quite correct. The air is thrown into sonorous vibration by friction against the borders of the opening. How the friction produces the sonorous vibrations in this case is not evident, for the sounds produced by the friction of other bodies evidently arises from the periodic adhesion of the body exerting the friction, as when the border of a glass is rubbed by the finger. How this intermission of adhesion or friction can take place between the air and the solid borders of an opening which do not themselves vibrate, is difficult to explain. That the motion of the air traversing the opening is periodically arrested

* See Muncke in Gehler's *Physikal. Wörterb.* viii. p. 383; and Cagniard la Tour, in Magendie's *Journal de Physiol.* t. x.

by the friction can be more easily imagined than proved. The possibility of the adhesion of air to water is evident, however, from the ripple (gekräuselten Wellen) which wind produces on the surface of water.*

It appears to me that Cagniard la Tour attributes too little importance to the oral cavity in his explanation of whistling. The analogy of whistling with the sound of flute-pipes, which he endeavours to disprove, appears to me to be very great. Savart has shown that musical sounds can be obtained from the mere mouth-piece of a pipe; so that in reality the sound is excited and the air thrown into vibrations in the mouth-piece of the instrument, and the vibrations are merely modified by the column of air in the tube of the pipe. The same seems to be the case in whistling; the cause of the vibration is the friction of the air against the borders of the opening, but the vibration there excited throws the whole column of air in the mouth into vibrations, and the vibrations of this column of air, by a reciprocal influence, determine the rapidity of the vibrations of the air at the orifice. The only difference between whistling and the sounds of a pipe is, that in whistling the whole column of air is in constant progressive motion through the tube and orifice; while in a pipe the air in the tube merely vibrates, and does not move as a current.

The analogy between whistling and the sounds of a pipe or flute is proved by the following facts. 1. The pitch of the note is raised by increasing the force of the current of air, the size of the orifice of the lips and the position of the tongue remaining the same; this is exactly in accordance with the effect of blowing with increased force into small pipes (see Appendix, page 18). 2. The pitch of the note may be modified by altering the size of the orifice of the lips in the same manner as the notes of pipes, by diminishing or increasing the size of the embouchure (see page 979). 3. The notes of whistling are rendered lower by retracting the point of the tongue,—higher by advancing it. The same changes are produced in the pitch of the notes of pipes by increasing or diminishing the length and diameter of the tube.

The notes produced by the jew's-harp, like those of whistling, vary, *cæteris paribus*, according to the form of the cavity of the mouth and position of the tongue. The vibrations which, in whistling, are produced by the friction of the air passing through the opening of the lips are, in the case of the jew's-harp, excited by striking the steel tongue, or by drawing the air forcibly into the mouth between the tongue and lateral bars of the instrument.†

* Weber, *Wellenlehre*, p. 33.

† [The variation of the tones of the jew's-harp, produced by altering the size of the cavity of the mouth, is thought by Mr. Wheatstone to be the result of the law pointed out by him,—that a column of air will vibrate, and produce sounds, whenever it is of such length that its vibrations are a multiple of those of the body originally vibrating.]

3. *Of the voice of mammalia and reptiles.*

The mode of production of the voice in *mammalia* is exactly the same as in man. The *chordæ vocales* can be seen vibrating in experiments on the larynx of the ox, and by relaxing them the notes become deep and loud. The superior ligaments of the glottis and the ventricles are wanting in the ruminantia; hence they cannot be essential to the production of deep notes.* The solidungula have a superior ligament of the glottis; in the horse the mucous membrane forms a semilunar fold also below the epiglottis, which passes across from one vocal cord to the other; this fold does not exist in the ass and mule.† Below the semilunar fold in the horse there is a funnel-shaped cavity; and above it, beneath the epiglottis, a second cavity, which in the ass and mule is more capacious: in the latter animals also the ventricles of the larynx are larger, and their openings narrow and situated nearer the epiglottis. The hog also has below the epiglottis a spacious membranous sac.‡

In the apes the essential form of the organ of voice does not vary, but the resounding walls frequently present peculiarities; such is the sac which exists in the orang-outang between the thyroid cartilage and os hyoides, and the membranous sacs which Cuvier found in the Mandrill, Pavian, and Macacos, below the os hyoides. The apparatus for the resonance of the voice is greatest, however, in the howling apes of the New World, the *Mycetes*; the os hyoides and thyroid cartilage are expanded so as to contain large cavities, which open into the ventricles of the larynx. Brandt has discovered, moreover, laryngo-pharyngeal sacs. The epiglottis in these apes has a very large size and peculiar form. In the *Sapajous* (*Ateles* and *Cebus*) a curved tube is formed by the increased size and altered forms of the cartilago *Wrisbergi* and epiglottis. The voice of these animals has a whistling character.§

The sounds produced by *reptiles and amphibia*, like the voice of *mammalia*, have their source in the larynx. Frogs, as well as the crocodile, have vocal cords. The small size of the organ of voice in the frog cannot make us wonder at the deepness of the tones it utters, since we know that membranous bands in a relaxed state and merely distended by the air will emit deep notes. In the male frog membranous sacs at

* See Lehfeldt's experiments on the larynx of different mammiferous animals, loc. cit.

† Cuvier, *Anat. Comparée*.—Gurlt, *Vergl. Anat. der Haussäugethiere*, ii. p. 167.

‡ The anatomy of the larynx of other orders of *mammalia* has been accurately described by Brandt in his *Diss. de Mammal. quorund. præsertim quadruman. vocis instrumento*. Berol. 1826-4, to which we refer for further information.

§ The use of the cartilagines cuneiformes in *mammalia*, where they are frequently very large, and of peculiar cartilages found in the larynx of mammiferous animals, has been explained by Brandt.

the sides of the neck become distended during the emission of the sound, and serve to increase its intensity. In the *Rana Pipa*, the larynx, in which, as in the other frogs, the bronchi terminate directly without the intervention of a trachea, forms a large cartilaginous box, in the interior of which are two solid rodlike bodies,* almost as long as the larynx itself: the anterior extremity of these bodies is fixed; their posterior extremity is free, and projects on each side towards the opening of the bronchus. The vocal sound is produced here by the vibration of rod-shaped tongues, which act like a tuning-fork; while in other animals of the same class the parts which emit the sound are membranous. If a small piece of cartilage, some lines in length, be fixed by one extremity, and a current of air directed from a small tube upon its edge at the other extremity, a humming sound is heard.

4. *Of the voice of birds.*

The *organ of voice in birds* † is the inferior larynx, which is formed by the union of several of the rings of the trachea. A process from the lowest of these rings projects downwards before and behind, and in most birds endued with voice a bony bar passes across from one process to the other, dividing the lower part of the trachea into two lateral halves, which form the openings into the bronchi. In the goose, and many other birds, there is a fold of membrane on the outer side only of each lateral compartment of the larynx; the mode in which this fold is formed is as follows:—Between the lower end of the larynx and the first ring of the trachea on each side, the tube is membranous, and the membrane which forms it is lax; but at the lower extremity and outer border of the larynx it is rendered tense by being attached to the anterior and posterior processes of the larynx above-mentioned: the tense fold thus formed—named by Cuvier the vocal ligament—does not, however, project far into the interior of the organ. In singing-birds there is also another membranous fold, called by Savart ‡ *membrana semilunaris*, at the inner border of each lateral compartment of the larynx; this fold is of greatest size in birds which can be taught to speak. M. Savart has described two other vocal cords at the commencement of each bronchus. The rings of the bronchi form only segments of a circle. The three first of these arches have a peculiar form, described and represented by Savart. Along the inner surface of the third arch runs a cord formed of a peculiar tissue, apparently elastic; this is the external lip of the glottis of singing-birds. The lip at the inner surface of the glottis is in these birds formed by a small cartilage, called by Savart cartilago

* Described by Mayer, *Nova Acta, Nat. cur.* xii. 2. 541.

† In the anatomical description we follow Cuvier and Savart, the researches of whom, particularly those of Savart, on this subject, have been so complete.

‡ Froriep's *Not.* 331.

arytenoidea, and by bands of the same substance as that which forms the external lip. These parts forming the internal lip of the bronchial glottis are contained in the membrane—*membrana tympaniformis* of Cuvier—which stretches from the cartilages of the bronchi to the transverse bony portion of the larynx. The *membrana tympaniformis* is continuous with the *membrana semilunaris* of the larynx, which can consequently be made tense through its medium; it is very small in some birds, as the ducks and geese, and the rings of the bronchi are then nearly complete: in singing-birds it extends, according to Savart's observation, as low as the fourth or fifth cartilage of the bronchus; but it is of greatest extent in birds which are capable of speaking. The larynx has special muscles, by which the first cartilage of the bronchi can be drawn up towards the larynx, or the distance between the vocal cords increased or diminished. In singing-birds there are five pairs of these muscles; parrots have three pairs, two to close and one to open the glottis, which in them is single, there being no transverse bony bar at the lower part of the larynx, but the first half-ring of the bronchus has such a form that it resembles a valve articulated before and behind to the larynx, into the cavity of which it can project considerably. In other birds, which have little power of modulating the voice,—as birds of prey, water-hens and water-rails, snipes, lapwings, gulls, the cormorant, kingfisher, goatsucker, heron, bittern, and cuckoo,—there is only one muscle approximating the half-ring of the bronchus to the trachea. Other birds, again, have no special muscle of the larynx, the trachea merely is capable of being considerably shortened by the *musculi sterno-tracheales* and *ypsilo-tracheales*; this is the condition of the *gallinæ*, and of ducks and geese among the *palmipedæ*. In the ducks and goosanders (*mergus*) the inferior larynx presents dilatations of its walls, and in the male bird is extended into a large unsymmetrical cavity, partly bony and partly membranous, which is evidently the source of the peculiar sound of the voice in the male sex.

The trachea in birds, which with the cavity of the mouth forms the tube or pipe placed in front of the organ of sound, is capable of great shortening by the space between the different rings being diminished, or even by the rings being received one within the other. In some birds, as the cock of the wood, Penelope crane, stork and crane, and particularly in the male of these birds, the trachea is longer than the neck, being thrown into convolutions; in the wild swan, indeed, a convolution of the trachea is lodged within the sternum. The forms of the trachea are various; sometimes it is cylindrical; at other times conical, becoming gradually wider towards the mouth, as in herons and cormorants. The trachea presents a sudden dilatation in the *Anas clangula* and *fusca*, and also in *Palamedea bispinosa*, according to Humboldt's

observation; gradual dilatations in the *Mergus* and male of the duck family.

*Theory of the voice in birds.**—The voice was proved to have its source in the inferior larynx by Cuvier, who observed that a blackbird, a magpie, and a duck were still able to utter cries when the trachea was divided; he stopped the upper portion of the divided trachea and kept the beak closed,—the cry was heard as before; even after the head of the duck was cut off, several sounds were uttered. These experiments, which constantly afford the same result, are confirmed by observations made on the larynx removed from the body of the bird. If air is blown into the bronchi of a duck, a sound exactly similar to the natural cry of the bird is produced; the same result is obtained by blowing into the trachea of the duck or goose, even when the bronchi have been cut away; as long as the very tense portion of the bronchial membrane which is situated at the lower border of the inferior larynx remains, (and it is not removed in tearing away the bronchi,) I never fail to produce sounds.

According to Cuvier's theory, the sounds issuing from the larynx of birds are rendered deeper by elongation and relaxation of the vocal folds or ligaments, and higher by shortening and tension; these means being aided by variations of the size of the opening, and the consequent alteration of the rapidity of the current of air. But Cuvier believed that merely the harmonics of the fundamental note, namely, the octave, fifth of the octave, the second octave, and the third and fifth of this octave, and so on, could be produced by alterations of the tension of the vocal ligaments. Here, however, Cuvier was in error; for since the notes emitted by membranous tongues become higher in the inverse ratio of the length of the tongues, and in the direct ratio of the square roots of the extending forces, and since the degree of tension may be varied to any fraction between 1, 4, and 16, all sounds between the harmonics, the vibrations of which stand in the ratio of 1, 2, and 3, may of course be produced by such tongues. Cuvier confounded the properties of a reed with those of the mouth-piece of a flute-pipe, from which the harmonic intervals are obtained by blasts of increasing intensity. The sounds which are not harmonics of the fundamental note are produced, Cuvier supposed, by shortening of the trachea; the tone above the fundamental note, for example, by the trachea being shortened $\frac{1}{3}$ th of its entire length, the harmonics of the notes thus obtained being produced by changes in the larynx without further alteration of the length of the trachea. To ascend, however, in this way through the intervals of an octave, the trachea would require to be shortened one half, which can scarcely be effected; but the defect is supplied by the size of the aperture of the upper larynx being varied, by which means the notes

* Cuvier, *Anat. Comparée*.—Savart, *Froriep's Not.* 331, 332.

may be raised nearly an octave, just as in a covered pipe the tones are raised in pitch in proportion as the occlusion of the lower opening is diminished. In comparing on this account the organ of voice to trumpets, the great naturalist again confounded flute-pipes with reed-pipes, to which class of instruments trumpets belong (see page 1000). In a reed-pipe, however, the sounds are not, as in flute-pipes, modified in pitch in an uniform ratio with the length of the tube, but in accordance with perfectly different laws. By M. Savart the organ of voice of birds, like that of man, is compared to a pipe in which the air alone is the seat of sonorous vibrations; and he regards the lower larynx as analogous to the mouth-piece of such a pipe, and not to the mouth-piece or reed of a reed-instrument. M. Savart has, however, himself showed, by his experiments on pipes of equal dimensions but different materials, that the walls of the trachea must have a great influence on the notes produced by the column of air (see page 1021).

It appears to me to be a question very difficult, and at present almost impossible to determine, whether the sounds of the voice in birds are produced, as in man, by the vibrations of a reed or tongue; or, as in mere flute-pipes, by vibrations of a column of air excited by friction against the lips of an opening. The simple organ of voice of many birds—the duck, goose, and others—is undoubtedly a reed-instrument. Not only can the vocal cord or band forming the outer margin of the opening in the larynx be seen to vibrate strongly, but the sound produced has also the greatest resemblance to a sound arising from the vibrations of membranes. (The same remark applies to all birds which utter notes of the same character, as ravens, which however belong to the class of singing-birds.) The length of the trachea of the goose has moreover a very subordinate influence on the note produced by blowing through the bronchi; and the same characteristic sound is heard as well when the trachea is very much shortened as when it is long. But whether the piping, whistling sounds of other birds are produced in the same way, and not in the manner of whistling by the mouth, is another question. To me it appears much more probable that these sounds also are produced by the vibration of tongues: for, in the first place, the vocal folds cannot during a certain action of the muscles escape being thrown into vibration, and even though the friction of the air have some share in the production of the sound, a compensation must ensue between the vibrations of the air and those of the vocal ligaments; and in that case the organ of voice in birds would not be completely analogous to a whistle or pipe, but would be in part constituted as a reed-instrument. Then, again, by blowing by means of a tube inserted into a bronchus through the lower larynx of some birds (the raven and starling), after separating it from the trachea, I can produce sounds which are not perceptibly altered (as in the human organ of

voice) by holding a tube in front of the larynx, the current of breath being uniformly gentle. The length of the trachea has, at all events in the goose, a very slight influence on the note produced by the lower larynx, just as the length of a tube placed in the front of the human larynx has but a very slight influence on the pitch of the notes obtained. The greater number of the notes of birds may evidently be elicited from the inferior larynx by varying the force of the blast, as Savart pointed out, which certainly agrees with the effect of blowing with varying force upon the notes of flute-pipes of the same size as the trachea of small singing-birds; but the same variation of the notes by varying the strength of the blast may be produced in reed-instruments with membranous tongues, and even in reeds with very delicate metallic tongues (see page 991).

The effect of the trachea on the notes may either be the same as that of the tubes of flute-pipes, or it may merely influence the notes in the manner of the tube of reed-instruments. Contraction of the superior opening of the trachea at the superior larynx may, as in pipes and reed-instruments, lower the note.

The membrana tympaniformis, which vibrates strongly during the production of sounds in the lower larynx, must have an influence on them; a relation of compensation must subsist between the internal vocal cord, the membrana semilunaris, and the membrana tympaniformis. This latter membrane is analogous to the vibrating membrane of a pipe formed of a reed-stalk.

V. *Sounds produced by fishes.*

Very few fishes, as the Trigla, Cottus, and Pogonias, are known to utter sounds. The anatomy of these fishes is sufficiently well known; but it is at present quite impossible to offer a satisfactory theory of the mode of generation of the sounds they produce. I must, therefore, confine myself to a short statement of the facts.

The Triglaæ emit a grunting sound when they are taken out of the water; no organ has been discovered in these animals to which the production of this noise can with certainty be attributed. Is it possible that the peculiar muscle of the air-bladder in these animals has a share in causing the sound? The Cottus, from which a sound is heard to proceed when pressure is made upon its body, has no air-bladder. In the Sciænoid family there are several fishes which emit sounds; but those most known are the Corvina ronchus and the Pogonias. The Pogonias has on this account acquired the name of Tambour. These fishes produce continued sounds under the water.* Their air-bladder is very large, as in most of the Sciænoid family which emit a sound; is covered

* The observations of Mitchell, White, Schoepf, and others, concerning these fishes, have been collected by Cuvier and Valenciennes.

by strong muscles; and has appendages which, according to Cuvier, pass between the ribs, and become imbedded in the muscles. In a *Pogonias fasciatus* which I examined, the viscera and air-bladder had unfortunately been removed: band-like fillets were attached to the ribs internally, and had probably been torn from the air-bladder; they were not, however hollow. The pavement-like teeth of the upper and lower palate-bones of these fishes are of extraordinary size.*

CHAPTER III.

OF SPEECH.†

BESIDES the musical tones formed in the larynx, a great number of other sounds can be produced in the vocal tube between the glottis and the external apertures of the air-passages, the combination of which into different groups to designate objects, properties, actions, &c. constitutes language. The languages do not employ all the sounds which can be produced in this manner, the combination of some with others being often difficult. Those sounds which are easy of combination enter for the most part into the formation of the greater number of languages. Each language contains a certain number of such sounds, but in no one are all brought together. On the contrary, different languages are characterised by the prevalence in them of certain classes of these sounds, while others are less frequent or altogether absent. It comes within the province of physiology to investigate the natural classification of the sounds of language. The attempts to form a natural system of the articulate sounds, instituted by grammarians, have been quite inadequate to the object, the principle of classification having been derived from properties which are not essential. The classification of the sounds of articulate speech, according to the organs by which they are formed,—for example, into the labial, dental, guttural, and lingual,—is faulty when

* The sounds produced by the *Sphinx atropos*, and the humming sounds of dipterous insects, will be found explained by R. Wagner, in Müller's *Archiv*. 1836, and by Burmeister, in Poggendorf's *Annal*. xxxviii. The *Acheta domestica* and *locustæ* also emit sounds. See Cuvier's *Règne Animal*, t. v. p. 184.

† The authors who may be consulted on the subject of speech are: J. Wallis, *De loquela s. sonorum formatione*, in C. Amman, *Surdus loquens*. Lugd. Bat. 1727.—Kratzenstein, *Tentamen resolvendi problema ab Acad. Sc. Petrop.* 1780; *propos.* Petrop. 4.—Kempelen, *Mechanismus der Menschlichen Sprache nebst der Beschreibung seiner sprechenden Maschine*. Wien, 1791, 8.—Reitter, *Methodenbuch zum Unterricht für Taubstumme*. Wien, 1828.—Rudolphi, *Physiologie*.—Chladni, in Gilbert's *Ann.* 1824, st. 2.—C. Mayer, in Meckel's *Archiv. für Anat. u. Physiol.* 1826.—R. Willis, in Poggendorf's *Annal*. xxiv. and *Transact. of Philos. Soc. of Cambridge*, vol. iii.—Heusinger, in his edition of Magendie's *Physiology*.—Purkinje, *Badania w przedmiocie fizyologii mowy Ludzkiej*. Kraków, 1836, 8. (*Forschungen über die Physiologie der Menschlichen Sprache*. Krakaw, 1836.)

carried farther than the distinction of the oral and nasal sounds; for sounds which are, according to physiological principles, in part quite different from each other, are thus classed together, and, moreover, for the formation of most sounds several parts of the mouth co-operate. The distinction of the mutes and liquids is in part founded on correct principles; but the application of these principles has been imperfect. Even the properties of the vowels, as contra-distinguished from the consonants, have not been properly estimated. Their essential character is usually considered to be that they are independent sounds, originally formed in the larynx, though modified in the mouth; while consonants are not formed in the larynx, and cannot be sounded perfectly unless conjoined with a vowel. The difference between vowels and consonants is, however, much less considerable than this; for all vowels, as well as the consonants, can be produced without a vocal tone, as in whispering; and, moreover, one whole class of consonants can, as we shall presently see, be uttered with a vocal sound as well as without this sound. The essential difference between vowels and consonants is of a very different nature. A main error in many of the attempts at classification of the articulate sounds has been the failing to pay sufficient attention to the circumstance of it being possible to form them without vocal tone, as in whispering; while to recognise the essential properties of the articulate sounds we must first examine them as they are produced in whispering, and then investigate which of them can also be uttered in a modified character conjoined with vocal tone. By this procedure we find two series of sounds: in one the sounds are mute, and cannot be uttered with a vocal tone; the sounds of the other series can be formed independently of voice, but are also capable of being uttered in conjunction with it. Another important character of some of the articulate sounds is that they are only of momentary duration, taking place during a sudden change in the conformation of the mouth, and are not capable of prolongation by a continued effusion of the breath ("strepitus incontinuis explosivus"); while others can be prolonged, *ad libitum*, as long as a particular disposition of the mouth and a constant expiration are maintained ("strepitus continuus").* All sounds of the first kind are insusceptible of combination with vocal tone ("intonation"), and are absolutely mute; nearly all the consonants of the second kind may be attended with "intonation." Peculiar modifications of the sounds are thus produced, but the absolutely mute consonants with "strepitus explosivus" may by aspiration be completely changed to other sounds.

* [Kempelen, in his experiments on the artificial production of articulate sounds, observed, that the vowel sounds were distinct only when contrasted with each other; and even in the natural voice, as Mr. Willis observes, "if any given vowel be prolonged by singing, it soon becomes impossible to distinguish what vowel it is." This is more remarkably the case with many of the continuous consonants than with the vowels.]

A. *Mute sounds of the whisper.*I. *Mute vowels.*

All the vowels with their nasal modifications can be expressed in a whisper without vocal tone. These mute vowel sounds differ, however, in some measure as to their mode of production from the consonants. All the mute consonants are formed in the vocal tube above the glottis, or in the cavity of the mouth or nose, by the mere rushing of the air between surfaces differently modified in disposition. But the sound of the vowels, even when mute, has its source in the glottis, though the vocal cords are not thrown into the vibrations necessary for the production of voice; and seems to be produced by the passage of the current of air between the relaxed vocal cords. That the whispered vowels are formed at the glottis, and not in the mouth, any one may satisfy himself by experiments in his own person. The same sound can be produced in the larynx when the mouth is closed, the nostrils being open, and the utterance of all vocal tone avoided. This sound, when the mouth is open, is so modified by varied form of the oral cavity as to assume the character of the vowels *a, e, i, o, u*.

The oral canal or cavity of the mouth assumes the same form for the articulation of each of the mute vowels as for the corresponding vowel when vocalized; the only difference in the two cases lies in the kind of sound emitted by the larynx. Kratzenstein and Kempelen have pointed out that the conditions necessary for changing one and the same sound into the different vowels are differences in the size of two parts—the oral canal and the oral opening; and the same is the case with regard to the mute vowels. By oral canal, Kempelen means here the space between the tongue and palate: for the pronunciation of certain vowels both the opening of the mouth and the space just mentioned are wide; for the pronunciation of other vowels both are contracted; and for others one is wide, the other contracted. Admitting five degrees of size, both of the opening of the mouth and of the space between the tongue and palate, Kempelen states the dimensions of these parts for the different vowels as follows:

<i>Vowel.</i>	<i>Sound.</i>	<i>Size of oral opening.</i>	<i>Size of oral canal.</i>
a	[English <i>a</i> in far]	5 . . .	3
e	[English <i>a</i> in name]	4 . . .	2
i	[English <i>e</i> in theme]	3 . . .	1
o	[as in English]	2 . . .	4
u	[like <i>oo</i> in cool]	1 . . .	5

The relation in which other vowel sounds stand to the above as to the size of these parts is easily ascertained.

It has been remarked by Purkinje that the conditions for the formation of some of the vowels, particularly of *a* and *e* [the two sounds of the English *a* in *far* and *name*] have not been quite correctly stated by Kempelen. The production of both these sounds depends principally on the form of the cavity of the throat between the root of the tongue and the pharynx; in both cases this space is large, but largest in the pronunciation of *e* [long *a*]: the size of the opening of the mouth is the same in the two cases; not different, as Kempelen states. The position which he ascribes to the lips in pronouncing *o* is also unnecessary.

The nasal "timbre" of the vowels *a*, *i*, *o*, and *æ*, as in the French words *sang*, *singulier*, *ombre*, and *œuvre*, is given by merely contracting the isthmus of the fauces and elevating the larynx.

II. *Mute consonants with "strepitus æqualis s. continuus." Continuous sounds.*

All consonants of this class can be pronounced with an uninterrupted sound, which continues as long as the expiration can be prolonged; the disposition of the parts within the mouth remaining throughout as at the commencement of the formation of the sound. The consonants of this kind are *h*, *m*, *n*, *ng*, *f*, *ch* [as in the Scotch word "*loch*," or like the *gh* in the word "*light*," as pronounced by the Scotch], *sch* [equivalent to the English *sh*], *s*, *r*, and *l*. They may be arranged in three orders.

1. Continuous oral sounds uttered with the whole oral canal open.—The only sound of this kind is the aspirate, *h*. This sound does not depend on any opposition offered by the walls of the oral cavity to the passage of the air; it is the most simple result of the resonance of the parietes of that cavity during expiration. The *h* does not exist in the Italian language except in a few words, as "*ho*," "*hai*," "*ha*," "*hanno*."

2. Continuous sounds produced by expiration through the nasal canal, which is quite open.—Such are *m*, *n*, and *ng*. During the pronunciation of these consonants the air passes simply through the nasal canal, the aperture of the mouth being closed either by the lips, or by the tongue being pressed against the palate. Here also there is no opposition offered to the passage of the air. In the pronunciation of all the three consonants of this order the cavity of the mouth forms a blind diverticulum of greater or less length from the throat and nasal canal. This diverticulum is largest during the utterance of *m*, smallest when *ng* is being pronounced. The mouth is closed by the lips while *m* is spoken, which has misled Rudolphi and others into the belief that it is a labial consonant,—but such it is not: the lips merely close the mouth; the sound of the letter is not produced by this act of closing the lips, but, after they are closed, by the simple passage of the air through the

nasal cavity, together with the resonance of the diverticulum formed by the cavity of the closed mouth. In forming *n*, the mouth is closed by the extremity of the tongue being pressed against the fore part of the palate.

Ng, or $\bar{n}$, exists as a well-marked consonant, and not a mere combination of the sounds of two consonants, in many languages. It is as clearly a simple sound as *m* and *n*; for example, in the words "sing" and "bang." In pronouncing it the passage of the mouth is closed more posteriorly than for *m* and *n*, namely, by the application of the dorsum of the tongue to the posterior part of the palate. The *ng* of the French language is formed still deeper in the throat.

3. Continuous oral sounds developed by the valve-like application of different parts of the mouth to each other.—Such are the consonants *f*, the German [and Scotch] *ch*, *sch* [or *sh*], *s*, *r*, and *l*.

The parts which are thus pressed in a valve-like manner one against the other, so as to oppose the passage of the air, may be the lips, the teeth, or the tongue and palate. For the pronunciation of *f* the lips are kept in the position of blowing. There are two modifications of this puffing or blowing sound, namely, the true *f* and the German *w* [resembling most nearly the English *v*].

For *f* the opening of the lips is more nearly round.

For the German *w* the lips are very nearly approximated, but leave a long cleft between each other.

[The *f* in English pronunciation is produced rather by the application of the lower lip to the upper teeth than of the two lips to each other; and the *v* differs from the *f* only in being less aspirated.]

Ch, the Greek χ . The sound which this consonant has in the German language does not exist in the French [nor in the English, but some of its modifications are met with in the Scotch and Irish dialects]. For its production the tongue is applied closely to the palate, and the air is pressed through the small space left between them. There are three modifications of the sound, according to the part of the palate to which the tongue is applied. In the first modification the fore part of the tongue is applied to the fore part of the palate, as in pronouncing the German words "lieblich" and "selig." (The sound of the Greek χ is expressed in German sometimes by the *ch*, and sometimes by *g*). In the second, the dorsum of the tongue is approximated to the middle of the palate; this sound is very different from the preceding, it is heard in the German words "tag," "suchen," "ach," &c. The third modification of this sound of *ch* is used by the Swiss, Tyrolese, and Dutch; to produce it, the dorsum of the tongue approaches the back part of the palate or the soft palate: the sound exists as "chet," Hebr., "cha," Arab.; and, according to Purkinje, in the Bohemian language. [The sounds of the *ch* in the Scotch word "loch," and of the *gh* in the Irish word

"lough," are perhaps identical with the second variety of the sound of the *ch*, here spoken of.]

The German *sch* [the English *sh*, and the French *ch*] is a very well-marked and simple sound; during the utterance of which the teeth are closely applied to each other, while the tip of the tongue lies behind them without touching them.

S. For this sound the teeth approach, or are in contact with each other, while the point of the tongue touches the lower teeth. The English *th* is a modification of this sound.

For the sound of *r* the tongue vibrates against the palate.

In the pronunciation of *l* the point of the tongue is applied closely to the palate, and the air escapes on either side between the tongue and cheeks, or it may escape only on one side.

III. *Mute consonants with "strepitus explosivus." Explosive sounds.*

These are the Greek β , γ , δ , and their modifications, π , κ , τ . They are the explosive sounds of Amman.

The organs of speech engaged in the formation of these sounds undergo a sudden change of position during their production; the sound commences with the closing of the mouth, and terminates with the opening of it. Hence these consonants cannot be prolonged *ad libitum*. The sound ceases as soon as the mouth is opened.

1. Simple explosive sounds, *b*, *d*, *g* (the hard *g* or gamma).

B. β . The lips are brought together so as to close the mouth, and separate at the moment that the air is expired.

D. δ . The mouth is closed by the tongue being applied to the anterior part of the palate or to the upper teeth, and opens with the escape of the breath.

G. γ . The momentary occlusion of the passage through the mouth takes place more posteriorly by the application of the back part of the dorsum of the tongue to the palate. It is only the hard *g* [as in "gold," "gag," "gun,"] corresponding to the Greek γ , that is thus pronounced. The palatal sound of the German *ch*, which is often written *g* [and the English *g* soft, as in "gentle," "gin,"] are produced in a different manner.

The mute or whispered sounds of *b*, *d*, *g*, are usually formed by the sudden opening of the vocal tube previously closed in the way we have described. They may, however, be produced likewise by the sudden occlusion.

2. Aspirate explosive sounds, *p*, *t*, *k*.

These are merely modifications of *b*, *d*, *g*, produced by a stronger aspiration during the opening of the previously closed passage of the mouth.*

* This explanation was given in my "Grundriss der Physiologie," in 1827.

All the principal sounds of articulate language are, as we have seen, capable of being pronounced in the manner of the mute or whispering speech. There are only a few modifications of the consonants which require for their formation an accompanying vocal tone; such are the German *j* [or English *y*], the French *j* and *ge*, the French [and English] *z*, and the vocalised *l* and *r*. In place of these vocalised consonants, corresponding mute consonants are produced when the former are attempted to be uttered in a whisper. Thus,

For the German *j* or English *y*, the German *ch* is produced.

- French *j* or *ge* . . . the English *sh* (the German *sch*).
- French or English *z* . . . the English *s*.
- vocalised *l* the mute *l*.
- vocalised *r* the mute *r*.

B. *The sounds of vocalised speech.*

In the vocalised speech some few consonants have still merely the character of whispered sounds, being incapable of combination with any vocal tone. Other consonants are in vocalised speech susceptible of two modes of pronunciation, the mute and the vocalised. The vowels have the vocal tone.

I. *Vowels*.—The disposition of the organs of speech is the same for the vocalised as for the mute pronunciation of the vowels; the vocal tone produced in the larynx by the vibrations of the vocal cords is modified in the throat, mouth, and oral opening into the different vowels. The proper diphthongs are combinations of two vowels. [The English *i* in its long sound is the equivalent of the German diphthong *ei*, and seems to be really a combination of two sounds. The sound of *i* cannot, like a true vowel, be prolonged *ad libitum*; but appears rather to result from the transition from a peculiar murmur to the sound of *e*, just as the diphthong *oy* or *oi* results from the transition from broad *a* to *e*].*

A peculiar murmuring sound accompanies several consonants, which does not resemble any of the vowels. This kind of intonation can be produced either with the mouth open or with it closed, the nasal passage being in the latter case open.

* The so-called mute *e*, the Hebraic *scheva*, which occurs in the German words “*habe*” and “*sage*,” at least in some dialects, is a peculiar vowel, approaching very near the sound of the whispered vowels. The vowels do not commonly occur as mute or whispered sounds in the open vocalised speech. There is, however, a trace of such sounds in the Slavonian dialects, for example, in the Polish language. In the word “*wab*” the *b* is followed by the sound of a mute or whispered *i* [or English *e*]. The same sign after other consonants indicates the mute sound of the same vowel; but from the mute *i* [*e* English] there is an easy transition to the sound of the German *ch*, which is produced by such a similar disposition of the oral tube. [The English *y* also, which, when pronounced in a whisper, is replaced by the German *ch*, seems to result from the transition from an aspirated *e* to the succeeding vowel.]

II. *Consonants which, in vocalised speech, are not accompanied with a vocal sound.*

1. The explosive *b, d, g* (γ), and their modifications *p, t, k*. It is quite impossible to combine the sounds of these consonants with an intonation of the voice. If it be attempted to pronounce them aloud, the intonation only follows them, and the result is the combination of the mute consonant with a vowel.

2. The only continuous consonant which cannot be pronounced in combination with a vocal sound is the aspirate *h*. The aspiration of the *h* ceases immediately that the vocal cords are thrown into sonorous vibrations.

III. *Consonants which, in vocalised language, can be pronounced either as mute sounds or with vocal intonation.*—These are all of the class of continuous consonants; namely, *f*, the German *ch*, *sch* [the English *sh*, and French *che*], *s, r, l, m, n, ng*. The vocalised sounds of these consonants are wanting in many languages; they exist in greatest number in the French language, in which they are sometimes expressed by special letters; for example, the vocalised *s* is written *z*, thus “zone” in a whisper is “sone;” the German *sch* [or English *sh*], vocalised, is written *j*, as in “jamais;” or else the vocal intonation of the consonant is expressed by the mute *e* being placed after it, as in words ending with *le, me, ne, and re*. The *e* in these words is not really pronounced as such, but merely expresses the intonation of the preceding consonant. The mute *e* after other consonants has no signification, unless to indicate that their pronunciation is to be changed; the French *ge* and *che*, for example, are the German *sch* [the English *sh*], while *g* before *a* is the real gamma.* The German language distinguishes in one case only a consonant with a vocal sound from its corresponding mute; the German *j* is the vocalised *ch*, as in “ja.” Kempelen observed that the German *j* was produced by the vocalisation of the *ch*; that the French *z* is a vocalised *s*, and that the French *j* is the German *sch*, with a vocal intonation.† [The mute *e* in the English language does not change the pronunciation of the preceding consonant, as in French words; the English *z*, which in the middle of a word has the sound of the French *z*, is in whispering also pronounced

* The sound of the German *ch* occurs in the French language only in combination with the “*l mouillé*,” for example in the word “*mouillé*,” where the *le* has the sound of *lyé* [written in German *ljé*], or, when pronounced in a whisper, of *lché* [the German *ch*].

† We gave the same statement of the parallel sounds of mute and intonated speech in our “*Grundriss der Physiologie*,” Bonn. 1827. Kempelen classes the consonants *l, m, n*, and *r* among the vocalised sounds, but they are certainly not always so; they are heard distinctly as true mute sounds in the vocalised speech. The consonants *b, d*, and *g*, which he also reckons amongst the intonated sounds, are as mute as the *p, t, k*, which he correctly classes among the mute consonants.

as *s*; the English *y*, which is equivalent to the German *j*, has the sound of the German *ch* when pronounced in a whisper, for example, in the word “yes.”]

The consonant *ng* can be vocalised *ad libitum*. The German *f* and *w* when vocalised have both the sound of *w* [or English *v*].

The French language is especially characterised by the prevalence of consonants accompanied by vocal intonations. It is the prevalence of the soft consonants with vocal intonations that gives the French language its beauty. It has, however, a degree of nasal monotony from the frequent use of the nasal consonants *m*, *n*, and *ng*, and particularly of the last-named, in constant combination with vowel sounds of nasal timbre to the exclusion of other vowels not of nasal character, with which the *ng* is associated in the English and German languages. Even where such combinations as *em* and *ing* occur in French words other nasal vowels are substituted in pronunciation, as in “empereur,” “singulier.”

[The following table contains Professor M ller’s classification of articulate sounds.]

		Mute.	Corresponding sounds with vocal intonation.
Consonants.	Vowels,	$\left\{ \begin{array}{l} a \\ e \\ i \\ o \\ u \end{array} \right.$	$\left\{ \begin{array}{l} a. \\ e. \\ i. \\ o. \\ u. \end{array} \right.$
	Continuous.	Aspirate <i>h</i> ,	
		Nasal. $\left\{ \begin{array}{l} m \\ n \\ ng \end{array} \right.$	$\left\{ \begin{array}{l} m. \\ n. \\ ng. \end{array} \right.$
		Oral. $\left\{ \begin{array}{l} f \\ v \text{ (the German } w) \\ ch \text{ } \chi, \text{ (the Scotch and German } ch) \\ sh \\ s \\ r \\ l \end{array} \right.$	$\left\{ \begin{array}{l} v \text{ (in German, } w). \\ v \text{ (in German, } w). \\ y \text{ English (in German, } j). \\ j \text{ French, as in “jamais.”} \\ z \text{ French, as in “zone.”} \\ r. \\ l. \end{array} \right.$
	Explosive.	Simple. $\left\{ \begin{array}{l} b. \\ g, \gamma. \\ d. \end{array} \right.$	
		Aspirate. $\left\{ \begin{array}{l} p. \\ k. \\ t. \end{array} \right.$	

The sounds which we have hitherto considered are the essential elements of all perfect languages; they have different signs in different languages, but that is a circumstance which it does not come within our purpose to consider. *Q*, *X*, and *Z* are not independent consonants, but compound sounds. [The *j*, soft *g* and *ch* of the English language are also compound sounds. The *j* and *g* being pronounced like the French *j* in “jamais” preceded by *d*; the *ch* like *t* followed by *sh*.]*

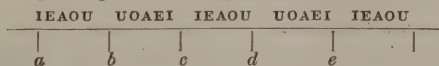
Besides the sounds of consonants which ordinarily enter into the

* On the comparative prevalence of the different sounds in different languages, consult Parkinje, loc. cit.

formation of languages, there are a number of other sounds capable of being formed in the mouth and throat. The smacking sounds which can be produced in separating the tongue from the teeth or palate, are said by Lichtenstein and Salt to occur in the language of the Hottentots and other African tribes.

The different sounds and tones of language being dependent on certain physical conditions, are of course capable of imitation by artificial contrivances. Some are produced very easily in this manner, as *b*, which is heard when the sound of the voice is made to pass into a cylindrical tube, before which the hand is held and then withdrawn; the German *w* [*v*] may be formed in the same way if the tube be a pipe with membranous tongue. Experiments relative to the artificial production of the articulate sounds have been made by Kratzenstein, Kempelen, and Mr. R. Willis.* They have succeeded in imitating a great part of the sounds used in speech. But these speaking-machines are always to a certain extent imperfect, since every simple and independent sound and consonant requires a special apparatus; and the combination of the different apparatus with a common tube for the supply of air, so as to form words, is exceedingly difficult. We cannot be surprised also at some birds, as the parrot and raven, being capable

* [Kratzenstein produced the vowel sounds by means of reed-tubes of curious forms. Kempelen employed a conical funnel-like tube, with a reed at its upper narrow extremity, and obtained the sounds of the different vowels by covering the lower wide opening to a greater or less extent. Repeating these experiments, Mr. Willis found that, with an instrument of the form Kempelen used, the vowels *u*, *o*, and *a* only could be produced, but that with a much shallower funnel the whole series, *u*, *o*, *a*, *e*, *i*, could be obtained. This induced him to try the effect of tubes of different length. The result he arrived at was, that the different vowel sounds may be produced by merely varying the length of the tube affixed to a reed. Let *a*, *b*, *b c*, *c d*, &c. in the diagram represent the lengths of a stopped pipe in unison with the reed. The letters above the line will indicate the length of the tube measured from *a*, by which the corresponding vowels were produced.



As the tube was lengthened from *a* to *b* the note of the reed assumed the characters of IEAOU; between *b* and *c* the series were heard again in the inverse order; and between *c* and *d* in the direct order again; and so on in cycles, which were a repetition of that between *b* and *d*.

The respective vowels in these cycles (*u o a e i, i e a o u*) stand in all cases at the same distance from the points *a*, *c*, and *e*, whatever the length of the wave of the reed, or of the portion of pipe in unison with the reed. Hence, if the pitch of the reed be high, and the length of pipe and column of air in unison with it consequently short, the vowels furthest distant from the points *a*, *c*, and *e* cannot be formed. And this, Mr. Willis remarks, is exactly the case in the human voice; female singers are unable to pronounce U and O on the higher notes of their voice. According to Mr. Willis, the peculiar vowel character of any sound is owing to that sound being accompanied by the musical note appropriate to the production of the vowel.]

of uttering articulate sounds, since their mouth has the same general conformation with parts which can act as valves. The mode of articulating sounds is, without doubt, learnt by these birds in the same way as by the human infant. The different sounds are first produced without any order or proposed end; but, while thus produced, the movements necessary for the formation of each become impressed on the sensorium, and are therefore readily associated again when the sound which they are calculated to give rise to is heard.

C. *Ventriloquism.*

The peculiarity of the particular mode of speaking which is so called, has been supposed by some physiologists, as M. Magendie, to consist merely in the varied modification of the sounds produced in the larynx, in imitation of the modifications which voice ordinarily suffers from distance, &c.; by others it is imagined to depend on some common cause, which modifies all the tones uttered, for example, on the articulation taking place during inspiration. This last is the view generally taken of the cause of ventriloquism. It is certainly possible to articulate during inspiration, though with difficulty; and the sounds thus produced have some similarity with the tones of the voice of the ventriloquist. But, nevertheless, I regard the opinion in question as erroneous; for the sounds uttered by the ventriloquist can be perfectly imitated much more easily by another method, which I am convinced must be adopted by the ventriloquists themselves. The method to which I allude consists in inspiring deeply, so as to protrude the abdominal viscera by the descent of the diaphragm, and then speaking while the expiration is performed very slowly through a very narrow glottis by means of the lateral parietes of the thorax alone, the diaphragm maintaining its depressed position. The timbre which the voice has in speaking during an expiration thus performed is that peculiar to ventriloquism. Sounds may be thus uttered which resemble the voice of a person calling from a distance.

A great part of the art of the ventriloquist, for example, in imitating the voices, coming from particular directions, consists merely in deceiving other senses than hearing. We never distinguish very readily the direction in which sounds reach our ear; and, when our attention is directed to a particular point, our imagination is very apt to refer to that point whatever sounds we may hear.

D. *Defective speech.*

The proper exercise of the faculty of speech presupposes the possession of a normally-formed oral cavity as well as a good sense of hearing. Imperfections of speech arise from a want of either of these requisites. An opening in the palate renders the formation of some sounds im-

possible, and gives to the voice a nasal timbre; want of teeth also renders the speech imperfect.*

By want of command, or loss of power of the tongue, speech is rendered indistinct and unintelligible. This is observed as a temporary consequence of intoxication, and as a permanent result of paralysis of the ninth nerve.

The speech may, however, be imperfect also from the sounds not following each other as they ought to do, though the individual sounds be pronounced perfectly; such is stammering. It consists in a momentary inability to pronounce a consonant or vowel, or to connect it with the preceding sounds. This impediment may occur either at the commencement or in the middle of a word. In the latter case, the commencement of the word is often several times repeated; the part of the word thus repeated may end with a vowel, and the difficulty then consists in connecting with this the following consonant; or it may be merely the commencing consonant which is repeated, and with which the succeeding vowel cannot be combined. The repetition of the commencement of the word, as Schulthess rightly remarks, is not the essential condition of stammering; it is merely a new attempt at overcoming the impediment. If the consonant preceding the impediment be one of the explosive class, (*b, d, g*, and *p, t, k*), which do not admit of a continuous pronunciation until the formation of the vowel is attained, it is more prone to be frequently repeated; thus, a person who stammers, says for "bitter," b-b-b-bitter. But if it be a continuous consonant as *m, n, ng, f, χ* [the German and Scotch *ch*], *sh, r, l*, or *s*, it is not necessarily repeated, because the sound of a continuous consonant can be prolonged *ad libitum*, until the vowel follows it; for example, in the word "laughing." It does, however, sometimes happen that the continuous consonant is repeated in such a case, and the word is pronounced l-l-l-l-laughing. Sometimes letters which do not belong to the word are involuntarily introduced.

Schulthess maintains that the stammering does not arise from any difficulty in the pronunciation of the consonants, but that the impediment attends the utterance of the vowels. This view is founded on good observations; but, though an improvement on the previous erroneous opinions, it goes further than facts justify, for the vowel is often formed while the following consonant cannot be combined with it. I knew a young man of distinguished mathematical attainments, who had previously stammered very badly, and in pronouncing his own name, was apt to say Te-tessot instead of Tessot. In many cases also the impediment attaches to the first consonant of a word; and here likewise the difficulty does not so much depend on the parts of the mouth which are engaged in articulation, as on the arrest of the passage of the air necessary for the pronunciation of a particular consonant, by the momentary closure of the glottis. This closure

* On defects in the formation of particular letters, see Kempelen and Schulthess, loc. cit.

of the glottis, the importance of which has been particularly pointed out by Dr. Arnott,* occurs only in the attempt to articulate particular sounds, by involuntary association, the supply of air for the articulation of other sounds not being impeded; the syllable preceding the arrest of speech can, for example, be frequently repeated. The essential cause of the impediment is always situated in the glottis, whether it be that the vocal cords do not give the requisite sound when it is a vowel which is attempted to be formed, or that the passage of air is arrested during the attempt at articulation in the mouth. In persons who stammer very badly there are evident signs of the struggle at the glottis, afforded by the impediment to expiration and by the congestion of blood in the head and veins of the neck. The essential cause of stammering is, therefore, clearly an unnatural associate movement in the larynx by consent with the movements of the mouth, or articulate movements. When the struggles of stammering are violent, associate movements are observed also in the face. It is the same condition as that of a person who wishes to move one particular muscle of his face, but on account of association of nervous action, or defect of the power of insulating the nervous influence, cannot do it without distorting all his features.†

I agree entirely with Dr. Arnott and Schulthess in considering the immediate cause of stammering to be a spasmodic affection of the glottis. This affection consists in a momentary closure of the aperture, partly by the approximation of the arytenoid cartilages and partly by the pressure of the muscoli thyreo-arytenoidei, which are capable of pressing the ligaments of the glottis into contact with each other. It must be remembered as a principle that this momentary spasm depends entirely on a morbid association of the muscles of the larynx with the movements of the organs of articulation. The position of the mouth for the pronunciation of *b* is assumed, and the lips can be separated in the manner proper for the utterance of the sound; but when this is done, or ought to be done, the breath is wanting,—it is arrested at the larynx. The natural indication, therefore, for the prevention of stammering is to attempt to bring more under the command of the will the associations between the movements of articulation and the movements of the larynx. One method of fulfilling this indication is the singing of the words, in which the attention is directed more to the action of the larynx than in ordinary speaking. Persons who stammer pronounce better in singing than in mere speaking.

A too low position of the tongue in the mouth appears to favour stammering. The method of treatment practised by Mad. Leigh consisted in preventing this position of the tongue, and in raising its point

* Elements of Physics, vol. i.

† See the remarks on associate nervous action and associate movements, at pages 683 and 928.

towards the palate. The practice of placing bodies under the tongue, which was known to the ancients, tended to the same object.

The method proposed by Dr. Arnott for the cure of stammering, whatever be the result of its practice, is, at all events, founded on a sound physiological view of the nature of the affection. "Had the edges of the glottis," says Dr. Arnott, "been visible, like the external lips of the mouth, the nature of stuttering would not so long have remained a mystery." The glottis is repeatedly closed in persons who stammer, and the cure of the affection must therefore be effected by conquering this morbid tendency to closure by voluntarily keeping it open as much as possible. For this purpose Dr. Arnott advises that the patient should connect all his words by an intonation of the voice continued between the different words, as is done by persons who speak with hesitation. This plan may afford some benefit, but cannot do everything; since the main impediment occurs in the middle of words themselves, and depends on the abnormal association of the movement of the larynx with certain movements of articulation. Were I called upon to advise a method of treatment in a case of stammering, I would recommend, in addition to Dr. Arnott's plan, the following procedure. I would let the patient practise himself in reading sentences in which all letters which cannot be pronounced with a vocal sound, namely the explosive consonants *b, d, g, p, t, and k*, were omitted, and only those consonants included which are susceptible of an accompanying intonation of the voice; and I would direct that all these letters should be pronounced with such a sound of the voice, and that their sound should be very much prolonged. By this means a mode of pronunciation would be attained in which the articulation would be constantly combined with vocalisation, and the glottis consequently never closed. When the stammerer had long practised himself in keeping the glottis open without intermission, even between the words by Dr. Arnott's method, and in maintaining the glottis open during and after the pronunciation of every consonant capable of vocalisation and of the vowels, he might proceed to the mute and continuous consonant *h*, and the explosive sounds *g, d, b, k, t, p*. In such a plan of treatment the patient himself would perceive the principle; while the ordinary method—that of Mad. Leigh—is mere groping in the dark, neither teacher nor pupil knowing the principle of the procedures.*

There is a kind of defect of speech essentially different from stammering, consisting in a protracted intonation of the voice between words, or the introduction of a more or less prolonged *a* or *au*,—nasal vowel sounds, or peculiar vocal sounds modified by a jingling character between the words, which themselves are correctly pronounced; for example, I . . . a . . . have. It is like the prolonged vibration of a musical

* See Schulthess, loc. cit. p. 166.

instrument beyond the required duration. These sounds form and facilitate the transition from one word to another, and they may frequently be produced as a means of transition ; although they, in many instances, also arise from hesitation or want of readiness of the ideas. This mode of speaking sometimes attends stammering, probably because the impediment to the commencement of the next word is avoided by this transition of sounds.

The formation of perfect vocal tones presupposes the possession of the sense of hearing. It is only with the greatest labour that individuals born deaf can learn to utter a series of harsh sounds. The deaf and dumb owe their want of speech to their deafness : they can by great labour learn the movements of articulation by means of their sight ; but their speech is never more than a series of harsh sounds, not adapted for human society, for they want the sense of hearing to regulate their articulation.

There is no nearer medium of connection between the faculties of speech and hearing than the brain, and it is not evident how nervous communications could be of service to either organ. The connection of the facial nerve with the lingual branch of the fifth can have no influence on speech or hearing ; for the facial nerve has nothing to do with hearing ; the lingual branch of the fifth nothing to do with speech. The nerve on which the movements of speech principally depend is the ninth nerve, which supplies all the muscles of the tongue ; the facial also has some share in articulation, at all events as regards the movements of the lips. Both the last-named nerves are engaged in physiognomical expression, since the automatic movements of the features as well as speech disclose in different ways what is passing in the mind. Both nerves appear to arise from the same nervous centre,—the olivary body.*

* See Retzius, Müller's Archiv. 1836.

BOOK THE FIFTH.

Of the Senses.

PRELIMINARY CONSIDERATIONS.

THE senses, by virtue of the peculiar properties of their several nerves, make us acquainted with the states of our own body, and they also inform us of the qualities and changes of external nature, as far as these give rise to changes in the condition of the nerves. Sensation is a property common to all the senses; but the kind ("*modus*,"") of sensation is different in each: thus we have the sensations of light, of sound, of taste, of smell, and of feeling, or touch. By feeling, or touch, we understand the peculiar kind of sensation of which the ordinary sensitive nerves generally—as, the *nervus trigeminus*, *vagus*, *glossopharyngeus*, and the spinal nerves,—are susceptible; the sensations of itching, of pleasure and pain, of heat and cold, and those excited by the act of touch in its more limited sense, are varieties of this mode of sensation. That which through the medium of our senses is actually perceived by the sensorium, is indeed merely a property or change of condition of our nerves; but the imagination and reason are ready to interpret the modifications in the state of the nerves produced by external influences as properties of the external bodies themselves. This mode of regarding sensations has become so habitual in the case of the senses which are more rarely affected by internal causes, that it is only on reflection that we perceive it to be erroneous. In the case of the sense of feeling or touch, on the contrary, where the peculiar sensations of the nerves perceived by the sensorium are excited as frequently by internal as by external causes, it is easily conceived that the feeling of pain or pleasure, for example, is a condition of the nerves, and not a property of the things which excite it. This leads us to the consideration of some general laws, a knowledge of which is necessary before entering on the physiology of the separate senses.

I. In the first place, it must be kept in mind that *external agencies can give rise to no kind of sensation which cannot also be produced by internal causes, exciting changes in the condition of our nerves.*

In the case of the sense of touch, this is at once evident. The sensations of the nerves of touch (or common sensibility) are those of cold and heat, pain and pleasure, and innumerable modifications of these, which are neither painful nor pleasurable, but yet have the same kind of

sensation as their element, though not in an extreme degree. All these sensations are constantly being produced by internal causes in all parts of our body endowed with sensitive nerves; they may also be excited by causes acting from without, but external agencies are not capable of adding any new element to their nature. The sensations of the nerves of touch are therefore states or qualities proper to themselves, and merely rendered manifest by exciting causes external or internal. The sensation of smell also may be perceived independently of the application of any odorous substance from without, the nerve of smell being thrown by an internal cause into the condition requisite for the production of the sensation. This perception of the sensation of odours without an external exciting cause, though not of frequent occurrence, has been many times observed in persons of an irritable nervous system; and the sense of taste is probably subject to the same affection, although it would always be difficult to determine whether the taste might not be owing to a change in the qualities of the saliva or mucus of the mouth; the sensation of nausea, however, which belongs to the sensations of taste, is certainly very often perceived as the result of a merely internal affection of the nerves. The sensations of the sense of vision, namely, colour, light, and darkness, are also perceived independently of all external exciting cause. In the state of the most perfect freedom from excitement, the optic nerve has no other sensation than that of darkness. The excited condition of the nerve is manifested, even while the eyes are closed, by the appearance of light, or luminous flashes, which are mere sensations of the nerve, and not owing to the presence of any matter of light, and consequently are not capable of illuminating any surrounding objects. Every one is aware how common it is to see bright colours while the eyes are closed, particularly in the morning when the irritability of the nerves is still considerable. These phenomena are very frequent in children after waking from sleep. Through the sense of vision, therefore, we receive from external nature no impressions which we may not also experience from internal excitement of our nerves; and it is evident that a person blind from infancy in consequence of opacity of the transparent media of the eye, must have a perfect internal conception of light and colours, provided the retina and optic nerve be free from lesion. The prevalent notions with regard to the wonderful sensations supposed to be experienced by persons blind from birth when their sight is restored by operation, are exaggerated and incorrect. The elements of the sensation of vision, namely, the sensations of light, colour, and darkness, must have been previously as well known to such persons as to those of whom the sight has always been perfect. If, moreover, we imagine a man to be from his birth surrounded merely by external objects destitute of all variety of colours, so that he could never receive

the impressions of colours from without, it is evident that the sense of vision might nevertheless have been no less perfect in him than in other men; for light and colours are innate endowments of his nature, and require merely a stimulus to render them manifest.

The sensations of hearing also are excited as well by internal as by external causes; for, whenever the auditory nerve is in a state of excitement, the sensations peculiar to it, as the sounds of ringing, humming, &c. are perceived. It is by such sensations that the diseases of the auditory nerve manifest themselves; and, even in less grave, transient affections of the nervous system, the sensations of humming and ringing in the ears afford evidence that the sense of hearing participates in the disturbance.

No further proof is wanting to show, that external influences give rise in our senses to no other sensations, than those which may be excited in the corresponding nerves by internal causes.

II. *The same internal cause excites in the different senses different sensations;—in each sense the sensations peculiar to it.*

One uniform internal cause acting on all the nerves of the senses in the same manner, is the accumulation of blood in the capillary vessels of the nerve, as in congestion and inflammation. This uniform cause excites in the retina, while the eyes are closed, the sensation of light and luminous flashes; in the auditory nerve, humming and ringing sounds; and in the nerves of feeling, the sensation of pain. In the same way, also, a narcotic substance introduced into the blood excites in the nerves of each sense peculiar symptoms; in the optic nerves the appearance of luminous sparks before the eyes; in the auditory nerves, “tinnitus aurium;” and in the common sensitive nerves the sensation of ants creeping over the surface.

III. *The same external cause also gives rise to different sensations in each sense, according to the special endowments of its nerve.*

The mechanical influence of a blow, concussion, or pressure excites, for example, in the eye the sensation of light and colours. It is well known that by exerting pressure upon the eye, when the eyelids are closed, we can give rise to the appearance of a luminous circle; by more gentle pressure the appearance of colours may be produced, and one colour may be made to change to another. Children, waking from sleep before daylight, frequently amuse themselves with these phenomena. The light thus produced has no existence external to the optic nerve, it is merely a sensation excited in it. However strongly we press upon the eye in the dark, so as to give rise to the appearance of luminous flashes, these flashes, being merely sensations, are incapable of illuminating external objects. Of this any one may easily convince himself by experiment. I have in repeated trials never been able, by

means of these luminous flashes in the eye, to recognise in the dark the nearest objects, or to see them better than before; nor could another person, while I produced by pressure on my eye the appearance of brilliant flashes, perceive in it the slightest trace of real light. (See page 93.)

The supposed emission of light by the eyes of animals has been already discussed in the Prolegomena, page 93. It is not, *à priori*, contrary to known laws, to suppose that the nerves of animals may develop luminous matter; and since we have in the retina of the eye an opportunity which we have nowhere else, of observing a nerve through transparent media without inflicting any injury on the animal, it would be here that such a phenomenon would be best observed. The fact of light being developed by the retina and nerves, even were it proved by experiment, would not, however, influence the explanation of the appearance of light produced in the eye by internal causes.

A mechanical influence excites also peculiar sensations of the auditory nerve; at all events, it has become a common saying, "to give a person what will make his ears ring," or "what will make his eyes flash fire," or "what will make him feel;" so that the same cause, a blow, produces in the nerves of hearing, sight, and feeling, the different sensations proper to these senses. It has not become a part of common language that a blow shall be given which will excite the sense of smell, or of taste; nor would such sayings be correct,* yet mechanical irritation of the soft palate, of the epiglottis and root of the tongue, excites the sensation of nausea. The action of sonorous bodies on the organ of hearing is entirely mechanical. A sudden mechanical impulse of the air upon the organ of hearing produces the sensation of a report of different degrees of intensity according to the violence of the impulse, just as an impulse upon the organ of vision gives rise to the sensation of light. If the action of the mechanical cause on the organ of hearing be of continued duration, the sound is also continued; and when caused by a rapid succession of uniform impulses, or vibrations, it has a musical character (see page 972). If we admit that the matter of light acts on bodies by mechanical oscillation, (the undulation theory,) we shall have another example of a mechanical influence, producing different effects on different senses. These undulations, which produce in the eye the

* [The influence of mechanical agency in exciting the nerve of taste to its peculiar reaction may be made quite perceptible; but the stimulus must be applied in a particular manner. If the end of the finger be made to strike quickly, but lightly, the surface of the tongue at its tip, or its edge near the tip, so as to affect not the substance of the organ, but merely the papillæ, a taste sometimes acid, sometimes saline, like the taste produced by electricity, will be distinctly perceived. The sensation of taste thus induced will sometimes continue several seconds after the application of the mechanical stimulus.]

sensation of light, have no such effect on other senses; but in the nerves of feeling they produce the sensation of warmth.*

The stimulus of electricity may serve as a second example, of a uniform cause giving rise in different nerves of sense to different sensations. A single pair of plates of different metals applied so as to include the eye within the circle, excites the sensation of a bright flash of light when the person experimented upon is in a dark room; and, even though the eye do not lie within the circle, if it be not distant from it,—as, for example, when one of the plates is applied to one of the eyelids, and the other to the interior of the mouth,—the same effect will be produced, owing to a part of the current of electricity being diverted to the eye. A more intense electric stimulus gives rise to more intense sensations of light. In the organ of hearing, electricity excites the sensation of sound. Volta states that, while his ears were included between the poles of a battery of forty pairs of plates, he heard a hissing and pulsatory sound, which continued as long as the circle was closed.† Ritter perceived a sound like that of the fiddle G at the moment of the closure of the galvanic circle.

The electricity of friction, developed by the electrical machine, excites in the olfactory nerves the odour of phosphorus. The application of plates of different metals to the tongue, gives rise to an acid or a saline taste, according to the length of the plates which are applied one above, and the other beneath the tongue. The facts detailed with regard to the other senses are sufficient to show that these latter phenomena cannot be attributed to decomposition of the salts of the saliva.

The effects of the action of electricity on the nerves of common sensation or feeling, are neither the sensation of light, of sound, of smell, nor of taste, but those proper to the nerves of feeling, namely, the sensations of pricking, of a blow, &c.

Chemical influences also probably produce different effects on different nerves of sense. We have, of course, but few facts illustrating their action on these nerves; but we know that in the sensitive nerves of the skin they excite the different kinds of common sensation,—as the sensations of burning, pain, and heat; in the organ of taste, sensations of taste; and, when volatile, in the nerves of smell, the sensations of odours. Without the infliction of great injury on the textures, it is impossible to apply chemical agents to the nerves of the higher senses, sight and hearing, except through the medium of the blood. Chemical substances introduced into the blood act on every nerve of sense, and excite in each a manifestation of its properties. Hence the internal

* [According to the generally received doctrines of physics, the heating power of light is due to calorific rays distinct from those which produce the sensations of light and colours in the eye.]

† Philos. Transact. 1800, p. 427.

sensations of light and sound, which are well known to result from the action of narcotics.

IV. *The peculiar sensations of each nerve of sense can be excited by several distinct causes internal and external.*

The facts on which this statement is founded have been already mentioned ; for we have seen that the sensation of light in the eye is excited :

1. By the undulations or emanations which from their action on the eye are called light, although they have many other actions than this ; for instance, they effect chemical changes, and are the means of maintaining the organic processes in plants.

2. By mechanical influences ; as concussion, or a blow.

3. By electricity.

4. By chemical agents, such as narcotics, digitalis, &c. which, being absorbed into the blood, give rise to the appearance of luminous sparks, &c. before the eyes independently of any external cause.

5. By the stimulus of the blood in the state of congestion.

The sensation of sound may be excited in the auditory nerve :

1. By mechanical influences, namely, by the vibrations of sonorous bodies imparted to the organ of hearing through the intervention of media capable of propagating them.

2. By electricity.

3. By chemical influences taken into the circulation ; such as the narcotics, or alterantia nervina.

4. By the stimulus of the blood.

The sensation of odours may be excited in the olfactory nerves :

1. By chemical influences of a volatile nature,—odorous substances.

2. By electricity.

The sensation of taste may be produced :

1. By chemical influences acting on the gustatory nerves either from without or through the medium of the blood ; for, according to Magendie, dogs taste milk injected into their blood-vessels, and begin to lap with their tongue.

2. By electricity.

3. By mechanical influences ; for we must refer to taste the sensation of nausea produced by mechanically irritating the velum palati, epiglottis, and root of the tongue.*

The sensations of the nerves of touch or feeling are excited :

1. By mechanical influences ; as sonorous vibrations, and contact of any kind.

2. By chemical influences.

3. By heat.

4. By electricity.

5. By the stimulus of the blood.

* See note to page 1062.

V. Sensation consists in the sensorium receiving through the medium of the nerves, and as the result of the action of an external cause, a knowledge of certain qualities or conditions, not of external bodies, but of the nerves of sense themselves ; and these qualities of the nerves of sense are in all different, the nerve of each sense having its own peculiar quality or energy.

The special susceptibility of the different nerves of sense for certain influences,—as of the optic nerve for light, of the auditory nerve for vibrations, and so on,—was formerly attributed to these nerves having each a specific irritability. But this hypothesis is evidently insufficient to explain all the facts. The nerves of the senses have assuredly a specific irritability for certain influences ; for many stimuli, which exert a violent action upon one organ of sense, have little or no effect upon another : for example, light, or vibrations so infinitely rapid as those of light, act only on the nerves of vision and common sensation ; slower vibrations, on the nerves of hearing and common sensation, but not upon those of vision ; odorous substances only upon the olfactory nerves. The external stimuli must therefore be adapted to the organ of sense—must be “homogeneous :” thus light is the stimulus adapted to the nerve of vision ; while vibrations of less rapidity, which act upon the auditory nerve, are not adapted to the optic nerve, or are indifferent to it ; for if the eye be touched with a tuning-fork while vibrating, a sensation of tremours is excited in the conjunctiva, but no sensation of light. We have seen, however, that one and the same stimulus, as electricity, will produce different sensations in the different nerves of the senses ; all the nerves are susceptible of its action, but the sensations in all are different. The same is the case with other stimuli, as chemical and mechanical influences. The hypothesis of a specific irritability of the nerves of the senses for certain stimuli, is therefore insufficient ; and we are compelled to ascribe, with Aristotle, peculiar energies to each nerve,—energies which are vital qualities of the nerve, just as contractility is the vital property of muscle. The truth of this has been rendered more and more evident in recent times by the investigation of the so-called “subjective” phenomena of the senses by Elliot, Darwin, Ritter, Goethe, Purkinje, and Hjort. Those phenomena of the senses, namely, are now styled “subjective,” which are produced, not by the usual stimulus adapted to the particular nerve of sense, but by others which do not usually act upon it. These important phenomena were long spoken of as “illusions of the senses,” and have been regarded in an erroneous point of view ; while they are really true actions of the senses, and must be studied as fundamental phenomena in investigations into their nature.

The sensation of sound, therefore, is the peculiar “energy” or “quality” of the auditory nerve ; the sensation of light and colours that of the optic nerve ; and so of the other nerves of sense. An exact

analysis of what takes place in the production of a sensation would of itself have led to this conclusion. The sensations of heat and cold, for example, make us acquainted with the existence of the imponderable matter of caloric, or of peculiar vibrations in the vicinity of our nerves of feeling. But the nature of this caloric cannot be elucidated by sensation, which is in reality merely a particular state of our nerves; it must be learnt by the study of the physical properties of this agent, namely, of the laws of its radiation, its development from the latent state, its property of combining with and producing expansion of other bodies, &c. All this again, however, does not explain the peculiarity of the sensation of warmth as a condition of the nerves. The simple fact devoid of all theory is this, that warmth, as a sensation, is produced whenever the matter of caloric acts upon the nerves of feeling; and that cold, as a sensation, results from this matter of caloric being abstracted from a nerve of feeling.

So, also, the sensation of sound is produced when a certain number of impulses or vibrations are imparted, within a certain time, to the auditory nerve: but sound, as we perceive it, is a very different thing from a succession of vibrations. The vibrations of a tuning-fork, which to the ear give the impression of sound, produce in a nerve of feeling or touch the sensation of tickling; something besides the vibrations must consequently be necessary for the production of the sensation of sound, and that something is possessed by the auditory nerve alone. Vision is to be regarded in the same manner. A difference in the intensity of the action of the imponderable agent, light, causes an inequality of sensation at different parts of the retina: whether this action consists in impulses or undulations, (the undulation theory,) or in an infinitely rapid current of imponderable matter, (the emanation theory,) is a question here of no importance. The sensation of moderate light is produced where the action of the imponderable agent on the retina is not intense; of bright light where its action is stronger, and of darkness or shade where the imponderable agent does not fall; and thus results a luminous image of determinate form according to the distribution of the parts of the retina differently acted on. Colour is also a property of the optic nerve; and when excited by external light, arises from the peculiarity of the so-called coloured rays, or of the oscillations necessary for the production of the impression of colour,—a peculiarity, the nature of which is not at present known. The nerves of taste and smell are capable of being excited to an infinite variety of sensations by external causes; but each taste is due to a determinate condition of the nerve excited by the external cause; and it is ridiculous to say that the property of acidity is communicated to the sensorium by the nerve of taste, while the acid acts equally upon the nerves of feeling, though it excites there no sensation of taste.

The essential nature of these conditions of the nerves, by virtue of which they see light and hear sound,—the essential nature of sound as a property of the auditory nerve, and of light as a property of the optic nerve, of taste, of smell, and of feeling,—remains, like the ultimate causes of natural phenomena generally, a problem incapable of solution. Respecting the nature of the sensation of the colour “blue,” for example, we can reason no farther; it is one of the many facts which mark the limits of our powers of mind. It would not advance the question to suppose the peculiar sensations of the different senses excited by one and the same cause, to result from the propagation of vibrations of the nervous principle of different rapidity to the sensorium. Such an hypothesis, if at all tenable, would find its first application in accounting for the different sensations of which a single sense is susceptible; for example, in explaining how the sensorium receives the different impressions of blue, red, and yellow, or of an acute and a grave tone, or of painful and pleasurable sensations, or of the sensations of heat and cold, or of the tastes of bitter, sweet, and acid. It is only with this application that the hypothesis is worthy of regard: tones of different degrees of acuteness are certainly produced by vibrations of sonorous bodies of different degrees of rapidity; and a slight contact of a solid body, which singly excites in a nerve of common sensation merely the simple sensation of touch, produces in the same nerve when repeated rapidly, as the vibrations of a sonorous body, the feeling of tickling; so that possibly a pleasurable sensation, even when it arises from internal causes independently of external influences, is due to the rapidity of the vibrations of the nervous principle in the nerves of feeling.

It was perhaps from an obscure acquaintance with the phenomena of the sensation of light from internal causes, that even the older philosophers derived their imperfect idea of the essential part which the eye itself plays in the sensations of light and colour. Such an idea can evidently be traced in Plato’s doctrine of vision in the *Timæus*. He says,—“*Illorum tamen instrumentorum primum ædificarunt (dii) ipsos oculos, luciferos quidem illos: quibus tantum ignis illigarunt quantum quidem comburere non valeret, lumen tamen proprium posset præbere: ut quidem perfectum quoddam diei corpus ita sit machinatus. Nam quod in nostris oculis est, germanâ quâdam et cognatâ cum die naturâ est: et quidem ita ut dii purum ejus ignem effecerint, illumque per oculos lævem densumque fluere, universo quidem at medio potius oculo ita impleto, ut aliud quidem, quantum nimirum crassius est, omne contineat: illud autem quod purum perspicuumque sit, tantum percolet. Quum autem diurna erit lux in ipso visus fluxu, tunc excidens simile ad simile compactum atque concretum, unum corpus conciliatum atque necessitudine quâdam devinctum constitutum est ad rectam oculorum inspectionem, quocunque contrarium fulciatur id quod intus incidit, ad*

id quod extra evenit. Quum autem oculus ad noctem accedit, a cognato igne deciditur, nam quum ad rem sibi dissimilem venit, et ipsam naturam quodammodo mutat atque extinguitur: nec amplius proximo aeri adnascitur: quippe qui ignem minimè habeat."

Aristotle's treatise on dreams,* contains views in themselves more correct, and stated in a more scientific form. His explanation of spectral appearances as the result of internal actions of the sense of vision, is quite on a level with the present state of science. He adduces indeed the observation since made by Spinoza, that images seen during sleep can still be perceived in the organs of vision after waking (cap. 3); and the varying colours of the ocular spectra produced by gazing at the sun were well known to him (cap. 2).

In the present more perfect state of the different branches of natural science, which are studied separately, and in part independently of each other, it still remains a task, well deserving the labour it would cost, to test the theories of fundamental phenomena, more especially of those which interest different sciences, such as the actions of light upon organic beings. But this would be a task of extreme difficulty, requiring for its proper performance a critical examination of the various facts.

During recent years, philosophy has done little in this field of inquiry. The manifestation of different objects to each other cannot express the nature of light; that it renders objects visible to us depends merely on our having an organ of vision with vital properties. And in this way many other agents have the same power of rendering objects manifest: were we endowed with as delicate an organic re-agent for electricity as for light, electricity would have the same influence as light in rendering manifest the corporeal world.

From the foregoing considerations we have learnt most clearly that the nerves of the senses are not mere conductors of the properties of bodies to our sensorium, and that we are made acquainted with external objects merely by virtue of certain properties of our nerves, and of their faculty of being affected in a greater or less degree by external bodies. Even the sensation of touch in our hands makes us acquainted, not absolutely with the state of the surfaces of the body touched, but with changes produced in the parts of our body affected by the act of touch. By imagination and reason a mere sensation is interpreted as something quite different.

The accuracy of our discrimination by means of the senses depends on the different manner in which the conditions of our nerves are affected by different bodies; but the preceding considerations show us the impossibility that our senses can ever reveal to us the true nature and essence of the material world. In our intercourse with external

* Of which I have given a translation in my paper, *Über die phantastischen Gesichts-erscheinungen*.

nature it is always our own sensations that we become acquainted with, and from them we form conceptions of the properties of external objects, which may be relatively correct; but we can never submit the nature of the objects themselves to that immediate perception to which the states of the different parts of our own body are subjected in the sensorium.

VI. *The nerve of each sense seems to be capable of one determinate kind of sensation only, and not of those proper to the other organs of sense; hence one nerve of sense cannot take the place and perform the function of the nerve of another sense.*

The sensation of each organ of sense may be increased in intensity till it becomes pleasurable, or till it becomes disagreeable, without the specific nature of the sensation being altered, or converted into that of another organ of sense. The sensation of dazzling light is an unpleasant sensation of the organ of vision; harmony of colours, an agreeable one. Harmonious and discordant sounds are agreeable and disagreeable sensations of the organ of hearing. The organs of taste and smell have their pleasant and unpleasant tastes and odours; the organ of touch its pleasurable and painful feelings. It appears, therefore, that, even in the most excited condition of an organ of sense, the sensation preserves its specific character. It is an admitted fact that the sensations of light, sound, taste, and odours, can be experienced only in their respective nerves; but in the case of common sensation this is not so evidently the case, for it is a question whether the sensation of pain may not be felt in the nerves of the higher senses,—whether, for example, violent irritation of the optic nerve may not give rise to the sensation of pain. This question is difficult of solution. There are filaments of the nerves of common sensation distributed in the nerves of the other organs of sense: the nostrils are supplied with nerves of common sensation from the second division of the nervus trigeminus in addition to the olfactory nerves; the tongue has common sensibility as well as taste, and may retain the one while it loses the other; the eye and organ of hearing likewise are similarly endowed.

To determine this question, it is necessary to institute experiments on the isolated nerves of special sense themselves. As far as such experiments have hitherto gone, they favour the view that the nerves of sense are susceptible of no other kind of sensation than that peculiar to each, and are not endowed with the faculty of common sensibility.

The olfactory nerves laid bare in the dog evince, when pricked, as Magendie observed, no sign of common sensibility; and the retina and optic nerve were also in Magendie's experiments * insusceptible of pain from mechanical injury. On the other hand, it has been observed that the division of the optic nerve in extirpation of the eye was attended

* Journal de Physiol. t. iv. p. 180.

with the perception of a great light, a fact of which my friend M. Tourtual assured me from his own observation. The luminous rings seen when the eyes are suddenly turned to one side are facts of the same kind; they are the result of the mechanical stretching of the optic nerve. In many of the cases in which extirpation of the eye is indicated, the optic nerve is itself so changed in structure as to be no longer capable of sensation; consequently, the above phenomenon must not be expected to be constant in its occurrence. In two cases of extirpation of the eye, performed in Berlin, it was not perceived. I am not aware, however, that the division of the optic nerve was in these instances attended with more pain than the other parts of the operation; while the division of a common sensitive nerve of the same thickness is productive of the most frightful pain, and in animals calls forth a sudden and loud cry.

An impression upon one nerve of sense may, it is true, give rise by reflection through the intervention of the brain to other sensations; for example, the sound of scratching glass excited in the auditory nerve, produces the feeling of cold creeping over the surface, "horripilatio," in the nerves of common sensation. And in the same way a dazzling sensation of light in the optic nerve, may possibly give rise by reflection to a painful impression on the sensitive nerves of the orbit and ball of the eye; in this way we may, at all events, explain the painful sensations in the eye which follow the impression of a very bright light.

With respect to the sense of smell, it is evident that Magendie was deceived in ascribing the power of distinguishing odours to the nasal branches of the fifth nerve, after the destruction of the olfactory nerves; since the stimuli which he applied—for instance, acetic acid, liquor ammoniæ, oil of lavender, and oil of dippel,—are themselves strong excitants of the common sensibility of the mucous membrane.* In all accurately observed cases of absence of the olfactory nerves, the true sense of smell has been wanting.†

No one can deny the possibility of the optic nerves influencing the nerves of the other senses, to the extent in which one nerve can act on another, through the medium of the brain. What an extensive affection of the nerves is seen in neuralgia! what manifold disturbances of the organs of sense result from a nervous condition which has its source in the viscera of the abdomen! How common in such cases are imperfection of vision, noises in the ears, &c.! although it is certain that much which is laid to the score of the abdomen has a much deeper source, namely, irritation of the spinal cord.

It is thus, also, that we must regard the sympathy of the optic nerve with the frontal branch of the fifth, and those cases of amaurosis ob-

* Eschricht, Magendie's *Journal de Physiol.* t. vi. p. 339.

† Eschricht, *loc. cit.*

served to follow injury of the frontal nerve; though it would perhaps be more correct to explain such affections, which according to my experience are now but rarely seen, as the result of concussion of the eye and optic nerve produced by a blow on the forehead.

The arguments adduced from anatomy in favour of the view that the function of one nerve of sense may be performed by another, have a very weak foundation. The optic nerve of the mole was supposed to be the orbitar branch of the fifth nerve; Koch and Henle have, however, shown that the mole has a special optic nerve, uncommonly small, it is true, but corresponding in size to the eye itself; and the same may be the case in the *Proteus anguinus*. Treviranus and E. H. Weber have demonstrated the independence of the acoustic nerve from the fifth nerve in fishes. Even the circumstance of fibres of different function being included in one sheath, is by no means an argument for the possibility of different sensations being transmitted by one conductor. It is on the supposition of such a union of different fibres in one sheath, that we may explain the existence in fishes of a *nervus accessorius nervi acoustici*, which arises sometimes separately from the brain, sometimes from the fifth nerve, and sometimes from the vagus;* and also the fact stated by Treviranus,† that in some birds the *nervus vestibuli* is a branch of the facial. The olfactory nerves were supposed to be absent in the dolphin, but rudiments of them have been found by Blainville, Mayer, and Treviranus;‡ so that it is not necessary to attribute the sense of smell in these animals to other nerves, and it is, moreover, by no means ascertained that they have any sense of smell.

Among the well-attested facts of physiology, again, there is not one to support the belief that one nerve of sense can assume the functions of another. The exaggeration of the sense of touch in the blind will not in these days be called seeing with the fingers; the accounts of the power of vision by the fingers and epigastrium, said to be possessed in the so-called magnetic state, appear to be mere fables, and the instances in which it has been pretended to practise it, cases of deception. The nerves of touch are capable of no other sensation than that of touch or feeling. Hence, also, no sounds can be heard except by the auditory nerve; the vibrations of bodies are perceived by the nerves of touch as mere tremours, a sensation wholly different in its nature from sound; though it is indeed even now not rare for the different modes of action of the vibrations of bodies upon the sense of hearing, and upon that of feeling, to be confounded. Without the organ of hearing with its vital endowments, there would be no such a thing as sound in the world, but merely vibrations; without the organ of sight, there would be no light, colour, nor darkness, but merely a correspond-

* E. H. Weber, *de Aure et Audit.* Lip. 1820, pp. 33. 101.

† *Zeitschrift für Physiol.* v.

‡ *Biologie*, v. 342.

ing presence or absence of the oscillations of the imponderable matter of light.

VII. *It is not known whether the essential cause of the peculiar "energy" of each nerve of sense is seated in the nerve itself, or in the parts of the brain and spinal cord with which it is connected; but it is certain that the central portions of the nerves included in the encephalon are susceptible of their peculiar sensations, independently of the more peripheral portion of the nervous cords which form the means of communication with the external organs of sense.*

The specific sensibility of the individual senses to particular stimuli, — owing to which vibrations of such rapidity or length as to produce sound are perceived, only by the senses of hearing and touch, and mere mechanical influences, scarcely at all by the sense of taste, — must be a property of the nerves themselves; but the peculiar mode of reaction of each sense, after the excitement of its nerve, may be due to either of two conditions. Either the nerves themselves may communicate impressions different in quality to the sensorium, which in every instance remains the same; or the vibrations of the nervous principle may in every nerve be the same and yet give rise to the perception of different sensations in the sensorium, owing to the parts of the latter with which the nerves are connected having different properties. The proof of either of these propositions I regard as at present impossible. Closely connected with this subject is the question of the existence of a difference in properties between the sensitive, motor, and organic nervous fibres. Do these fibres differ from each other by the nervous principle in each having a peculiar mode of oscillation? or are their different actions due to the parts with which they are connected as conductors? All that can be advanced with regard to this problem in the present state of our knowledge will be found at page 723.

It is, however, ascertained, beyond a doubt, that certain parts of the brain participate, at least, in the peculiar energies of the senses; for pressure on the brain has been frequently observed to cause the sensation of light. Luminous spectra may still be excited by internal causes after complete amaurosis of the retina.* Alex. von Humboldt † states that, in a man who had lost one eye, he produced, by means of galvanism, luminous appearances on the blind side. And Luicke ‡ relates the case of a patient who, after the extirpation of the eye for fungoid disease, perceived all kinds of luminous appearances independently of external objects, and was so teased by them as to imagine he really saw them with his eyes. When he closed the remaining sound eye, he per-

* See the examples given in my treatise, *Über die phantastischen Gesichtserscheinungen*. Cobl. 1826.

† Die gereizte Muskel- und Nerven-faser, t. ii. 444.

‡ De Fungo medullari. Lips. 1834.

ceived different images—such as lights, circles of fire, many dancing figures, &c.—floating before the orbit whence the eye had been removed. The sensations (which are analogous to those referred to a limb lost by amputation) continued for several days.

Sometimes, also, sensations and violent pains are felt in limbs quite devoid of sensibility to external impressions (see page 692). It is probable that here also the central organs are the source of the sensations. Since, therefore, the peculiar energies of the senses are possessed by certain portions of the sensorium, the question really requiring solution is, Whether the nerves, which are the conductors of the external impressions, participate or not in these properties or “energies.” This question cannot at present be answered; for the facts that are known may be explained on either supposition. That sensations arising from internal causes are often felt in peripheral parts, cannot be regarded as an argument for the nerves possessing the special sensitive energies; since it is known that affections even of the central organs of the nervous system are often manifested in peripheral parts of the body.

VIII. *The immediate objects of the perception of our senses are merely particular states induced in the nerves, and felt as sensations either by the nerves themselves or by the sensorium; but inasmuch as the nerves of the senses are material bodies, and therefore participate in the properties of matter generally occupying space, being susceptible of vibratory motion, and capable of being changed chemically as well as by the action of heat and electricity, they make known to the sensorium, by virtue of the changes thus produced in them by external causes, not merely their own condition, but also properties and changes of condition of external bodies. The information thus obtained by the senses concerning external nature, varies in each sense, having a relation to the qualities or energies of the nerve.*

Qualities which are to be regarded rather as sensations or modes of reaction of the nerves of sense, are light, colour, the bitter and sweet tastes, pleasant and unpleasant odours, painful and pleasant impressions on the nerves of touch, cold and warmth: properties which may belong wholly to external nature are “extension,” progressive and tremulous motion, and chemical change.

All the senses are not equally adapted to impart the idea of “extension” to the sensorium. The nerve of vision and the nerve of touch, being capable of an exact perception of this property in themselves, make us acquainted with it in external bodies. In the nerves of taste, the sensation of extension is less distinct, but is not altogether deficient; thus we are capable of distinguishing whether the seat of a bitter or sweet taste be the tongue, the palate, or the fauces. In the sense of touch and sight, however, the perception of space is most acute. The retina of the optic nerve has a structure especially adapted for this perception; for the ends of the nervous fibres in the retina are, as Treviranus disco-

vered, so arranged as to be at last perpendicular to its inner surface, and by their papillar extremities form a pavement-like composite membrane. On the great number of these terminal fibrils depends the delicate power of discriminating the position of bodies in space possessed by the sense of vision; for each fibre represents a greater or less field of the visible world, and imparts the impression of it to the sensorium.

The sense of touch has a much more extended sphere of action for the perception of space than has the sense of vision; but its perception of this quality of external bodies is much less accurate, and considerable portions of the surface of the body or skin are in many instances represented in the sensorium by very few nervous fibres; hence, in many parts of the surface, impressions on two points considerably removed from each other are, as E. H. Weber has shown, felt as one impression. Although the senses of vision, touch, and taste are all capable of perceiving the property of extension in space, yet the quality of the sensations which give the conception of extension is different in each of these senses; the sensation in one is an image of which the essential quality is light; in another, a perception of extension with any of the modifications of the quality of touch, between pain, cold, heat, and pleasure; in the third, a perception of extension with the quality of taste.

The external cause which excites in the organ of sense the sensation which conveys also the notion of extension, may be various. In the organ of vision it is usually the external light, but a concussion given to the eye by an external body may also be the cause; for example, if a determinate portion of the retina is pressed upon, a luminous spectrum is produced at that part, which will occupy a definite portion of the field of vision. Even electricity applied to the eyes can give rise to images of definite extent and form, such as lines of fire, the position of which varies according to the position of the poles of the galvanic battery: to the consideration of these phenomena we shall return. Light also may excite in the organ of touch a sensation with definite extent; for instance, the sensation of the parts warmed by the light of the sun has its limits as to extent. But ordinarily the impressions which inform us of the qualities and conditions of external bodies through the medium of the sense of touch, are mechanical contact, friction, concussion, pressure, or the communication of the vibrations of bodies, which we feel as tremours. By means of mechanical impressions on the sense of touch we obtain the first and most important information regarding the form and density of bodies, of which information reason afterwards makes us to interpret the perceptions of the other senses.

The distribution of nerves of common sensation throughout the entire mass of the limbs, indeed throughout most parts of our body, gives to our sense of touch the faculty of distinguishing the extension of our own

body in all its dimensions; for each point in which a nervous fibre terminates is represented in the sensorium. Collision with other bodies also, if forcible enough, may excite sensation to a certain depth in the mass of our body, and produce the perception of contusion in all the dimensions of the "cube." Usually, however, the three senses which make us acquainted with the space occupied by bodies, submit to our perception the property of superficial extension only, owing to the exciting causes acting only on the sentient surfaces. The sense of touch has, however, here this advantage over the sense of vision, that the parts endowed with it can be made to embrace a body in several directions; and although the sensation even then affords essentially only a perception of superficial extension, namely, of that of the surface of our body corresponding to the surfaces of the object, yet the mind, by taking into account the movements required for the embrace of the object, obtains from a sensation of superficial extent an idea of a body with a certain cubic capacity.

There exists in this respect less real difference between the sense of vision and that of touch than is generally supposed. To place them on an equality, it is only requisite that the eye should be able to change its position so as to look towards the different surfaces of an object; and this defect can be supplied by changing the relative position of our body and the object.*

The sense of hearing is almost totally incapable of perceiving the quality of extension; and for this reason, that the organ of hearing has no perception of its own extension. The cause of this difference between the senses is not known. The retina, even when the subject of no excitement from without, perceives its own extension and locality as darkness before the eyes. The organ of smell is sensible at least of the organ in which the odours are perceived, and is conscious of the whole cavity of the nostrils being occupied by a penetrating odour; we cannot make the odorous substance act on less than the entire nasal cavity. With respect to the sense of hearing, on the contrary, we have no perception at all of the part at which the sound is heard.

The sensation of motion is, like motion itself, of two kinds,—progressive and vibratory. The faculty of the perception of progressive motion is enjoyed in different manners by the three senses of vision, touch, and taste,—by those senses, therefore, which are capable of recognising extension in space generally, on which capability the former faculty is indeed dependent, and of which it is the mere result. An impression is perceived travelling from one part of the retina to another, and the movement of the image is interpreted by the imagination as motion of the object; the same is the case in the sense of touch. The

* [See the remarks on the estimation of the form of objects by vision in the third chapter of the section on vision.]

movement of a sensation of taste over the surface of the organ of taste can also be recognised.

The motion of tremors, or vibrations, is perceived by several senses. This faculty is most evident in the cases of hearing and touch; but even the retina and optic nerve appear to be capable of distinguishing such impressions. In the first place, with regard to the sense of hearing, it is known that vibrations communicated through the conducting apparatus of the ear, and lastly through the fluid of the labyrinth to the auditory nerve, are, if rapid, perceived merely as a continuous tone, the acuteness of which varies with the rapidity of succession of the vibrations; but, if they succeed each other slowly, the auditory nerve becomes to a certain degree sensible of the successive vibrations as an intermittent sound, and not merely of the general impression as a continued tone.

The vibrations which in the organ of hearing give rise to the sensation of sound, are perceived by nerves of touch in the skin as tremors frequently attended with the general impression of tickling; for instance, when a vibrating body, such as a tuning-fork, is approximated to a very sensible part of the surface. These are completely parallel phenomena to those produced by vibrations in the organ of hearing. Just as the latter organ perceives the impulses of a vibrating body separately as a series of unmusical sounds, and their rapid succession as a continuous tone, so the nerve of touch is sensible of distinct tremors, and if the vibrations succeed each other with sufficient rapidity, becomes the seat of the itching or tickling sensation peculiar to the sense of touch.

The experiments of Savart with the toothed wheel, and those of Cagniard la Tour with the siren, (see page 973,) have proved that the undulatory motion of vibrations is not necessary for the production of the sensation of sound in the organ of hearing, and that a rapid succession of mere impulses has the same effect, producing a musical note. In this respect, also, the action of the impulses of a body upon the nerves of touch forms a parallel to the phenomena produced in the organ of hearing; for the nerves of touch, brought into contact with a vibrating tuning-fork, receives a succession of impulses, of which each singly would not produce the sensation of tickling or itching.

The faculty of discerning the rate of succession of impressions is possessed by all the senses, though in a high degree only by the auditory nerves, in which its delicacy is very remarkable.

The instrument invented by M. Savart, in which tones are produced by the friction of the teeth of a revolving wheel against a hard body, has afforded the means of determining more accurately than was before possible the deepest and most acute notes perceptible by the ear. Savart has shown that tones which correspond to 24,000 impulses, or 48,000 simple vibrations, in a second, if of proper intensity, may still be heard.

Two impulses succeeding each other, or four successive vibrations, are sufficient to form a tone of which the pitch can be compared with that of other tones; that is to say, a tone which, if continued a second, would require 1000 impulses to produce it, will be recognisable if only two of the impulses are heard, and will be distinguishable from another sound which in a second would have 2000, or more or less impulses. From this it results that the sense of hearing can discriminate the interval of $\frac{1}{12000}$ of a second, since 24,000 impulses in a second upon Savart's instrument produced the most acute sound which could be perceived by the ear.

The eye can communicate to the sensorium the image of a vibrating body, and can distinguish the vibrations when they are very slow; but here the vibrations are not communicated to the optic nerve in such a manner that the latter repeats them, or that it receives their impulses; while in the ear the vibrations can be imparted directly to the auditory nerve, in consequence of this nerve being spread out on parts which contain the "fluid of the labyrinth." The optic nerve is not in the condition either to propagate or to receive vibrations, such as those of a sonorous body; to adapt it for such a purpose, it would require to be spread out, like the auditory nerves, upon sac-like membranes, filled and surrounded externally with fluid, and to have connected with it an apparatus for conducting the vibrations from without. If the optic nerve were, like the nerves of hearing and touch, capable of the perception of vibrations, the effect of the propagation of the vibration of an external body through the air to the retina would be a general appearance of light, just as sound is the result in the auditory nerve. I have already mentioned that the impulses of a vibrating tuning-fork brought into contact with the eye, are not adequate to excite the peculiar sensibility of the optic nerve. The cause of this may be either that the impulses are too feeble, or that they succeed each other too slowly. The feebleness of the impulses, which do not strike immediately upon the retina, is probably a principal cause; for a stronger impulse upon those parts of the eye where the retina exists, produces the sensation of light. It is possible, also, that very feeble impulses, if repeated with much greater rapidity, and acting on the retina itself, would excite its peculiar sensation—light. Such is the mode of action of external light upon the eye according to the "undulation theory," which has gained increased probability during the later steps of the science of physics. Newton* applied the theory of the undulations of light to the explanation of vision. According to the "undulatory theory," colours are the result of the different rapidity of the vibration and length of the undulations. The undulations which excite in the eye the sensation of violet, are the shortest; according to

* Optics. London, 1704, p. 135. Query 12.

Herschell's calculation, their length is 0·0000167 of an inch, and their number in a second is 727,000000,000000. The undulations of the red ray are the longest; their length being 0·0000266, and their number in a second 458,000000,000000. The vibrations of bodies which excite the sensation of sound in our sense of hearing are much slower. The column of air of the thirty-two feet organ-pipe vibrates thirty-two times in a second; and, according to M. Savart, tones are perceptible which result from seven or eight impulses only during a second, each impulse having a duration of $\frac{1}{16}$ of a second.

We are made acquainted with chemical actions by several senses, but principally by taste, smell, and touch, and by each of these senses in the mode proper to it. Volatile bodies disturbing the conditions of the nerves by a chemical action, exert the greatest influence upon the organ of smell; and many matters act on that sense which produce no impression upon the organs of taste and touch,—for example, many odorous substances, as the vapours of metals, of lead for instance, and of many minerals, &c.

It cannot, however, be stated as a general rule that volatile substances are perceived only by the sense of smell; for the same substances are also capable of impressing the senses of touch and taste, provided they are of a nature adapted to disturb chemically the condition of those organs, and in the case of the organ of taste are dissolved by the fluids covering it. Some volatile substances—as, the vapours of horse-radish and mustard, and acrid suffocating gases,—act very powerfully upon the common sensitive nerves of certain tracts of mucous membrane, as the conjunctiva and the mucous membrane of the lungs, exciting merely modifications of common feeling; many volatile matters also excite the sensations of burning, pain, &c. in the organ of touch when the skin is denuded of its epidermis.

It is not known whether fluid bodies are capable of exciting the peculiar energy of the organ of smell [in man]; and, owing to the position of the organ, we have little opportunity of deciding the question by experiment. Although nothing of the kind has ever hitherto been observed in man, it is not *à priori* to be regarded as impossible, since even volatile substances must be dissolved by the fluids of the mucous surface of the organ of smell before they can act on the olfactory nerves. Fishes, however, afford us a direct example of smell being excited by substances in the fluid state; and I cannot conceive why the nerves of smell in any animal should not be excited to their peculiar sensation by a fluid which excites in the nerves of taste the sensation of taste. The perceptions of odour in the air and water bear the same relation to each other as respiration in the air and water.

Fluid bodies, applied to the organs of touch and taste, produce chemical disturbances in their nerves, which excite in each a different sen-

sation; mustard, alkalies, acids, and salts, produce upon the skin, and upon the tongue, totally different effects. Their chemical action must primarily be the same; but the reaction excited differs according to the property of the nerves. On the tongue, however, both results are most probably produced in different nervous fibres at the same time, and by the same substance. Of all the nerves of sense, that of taste is most exposed to chemical influences, and is most affected by very slight modifications of the chemical constitution of bodies. The different conditions as to sensation, into which the nerves of touch can be thrown by chemical agents, are not by any means so numerous; moreover, these nerves are, at least upon the skin, (not on the mucous membranes,) protected from chemical influences by the epidermis.

In consequence of their contact with and reaction against external chemical influences, the three senses, smell, taste, and touch, become important instruments for the distinction and recognition of different substances, although neither of them reveals to us anything of their internal properties. The impressions produced on the senses by bodies similarly constituted are not always the same, and those produced by bodies of different chemical constitution are not constantly different.

The senses of sight and hearing are not exposed to the action of chemical influences from without; but it must not thence be concluded that they are insusceptible of excitement by such influences.

An important difference between the senses has reference to the proximity or distance of the bodies concerning which they give us information. Strictly speaking, the senses make us conscious only of that which is immediately present in them. By the eye we do not really perceive the luminous body; but the ends of the rays emitted from it strike the retina, and the parts of that membrane thus acted on become the seat of sensation. By the ear we do not feel the vibrating body, but merely the impulses transmitted to it from that body. Our imagination influences and modifies so powerfully the idea communicated to our sensorium by the act of vision, that this sense appears to us to have an action exterior to our body, and in place of the images depicted on the surface of the retina, the imagination conceives the idea of real objects; the image of a country, which occupies the space of a window, seems to the imagination an immediate perception of the different near and distant objects. In the senses of smell, taste, and touch, the imagination cannot have so great an influence: we refer, it is true, the sensations in the nerves to the objects themselves; but, since the objects excite the sensations of taste and touch by immediate contact, we become on reflection immediately conscious that our notions concerning the properties of the bodies are derived with only a relative degree of certainty from the affections which they induce in our organs of sense.

IX. *That sensations are referred from their proper seat towards the exterior, is owing, not to anything in the nature of the nerves themselves, but to the accompanying idea derived from experience.*

To know the first independent action of our senses distinct from the results of their education, it would be necessary that we had a full recollection of the first impressions made upon them independently of the ideas obtained through their means. This is impossible. Obscure ideas arise even from the first impressions on the senses of the child. It only remains for us then to analyse the act of sensation and the idea with reference to their real import. Doing this, we find in the act of the mind which accompanies sensation, opposed to each other, *the perceiving conscious subject*, or self, of the sentient body whose conditions, whether internal or determined from without, are objects for this “conscious self,” and the *external world*, with which the sentient body is brought into collision. To the mental consciousness,—to the “self” of the animal being,—every sensation, every motive from without, every “passion” in the logical sense, is something external. The “self” of the individual opposes itself as a free “subject” to the most intense sensations,—to the most tormenting pains. The limb which gives us pain can be removed without the integrity of the individual spirit being diminished; the “self” of the being may be deprived of most of the limbs (parts) of the organic body, and yet be itself as perfect as before; but we have thus far made no distinction between the “exterior” which the organised limbs of our body form in relation to the consciousness of our “self,” and the “exterior” which the external world itself forms with regard to our body. The origin of this distinction can be recognised most easily in the sense of touch, which is the first to come into collision with the external world. If we imagine a human being, in which—as in the *fœtus* in utero, for example,—the sense of vision has never received any impressions, and in which sensations of touch merely have been excited by impressions made upon its body from without, it is evident that the first obscure idea excited could be no other than that of a sentient passive “self” in contradistinction to something acting upon it. The uterus, which compels the child to assume a determined position, and gives rise to sensations in it, is also the means of exciting in the sensorium of the child the consciousness of something thus distinct from itself and external to it. But how is the idea of two “exteriors,”—of that which the limbs of the child’s body forms in relation to its internal self, and of the true exterior world,—developed? In a twofold manner. In the first place, the child governs the movements of its limbs, and thus perceives that they are instruments subject to the use and government of its internal “self;” while the resistance which it meets with around is not subject to its will

and therefore gives it the idea of an absolute exterior. Secondly, the child will perceive a difference in the sensations produced, according as two parts of its own body touch each other, or as one part of its body only meets with resistance from without. In the first instance, where one arm, for example, touches the other, the resistance is afforded by a part of the child's own body, and the limb thus giving the resistance becomes the subject of sensation as well as the other. The two limbs are in this case external objects of perception, and percipient at the same time. In the second instance, the resisting body will be represented to the mind as something external and foreign to the living body, and not subject to the internal "self." Thus will arise in the mind of the child the idea of a resistance which one part of its own body can offer to other parts of its body, and at the same time the idea of a resistance offered to its body by an absolute "exterior." In this way is gained the idea of an external world as the cause of sensations. Though the sensations of the being actually inform him only of the states of himself, of his nerves, and of his skin, acted on by external impressions, yet, henceforth, the idea of the perception of the external cause becomes inseparably associated with the sensation of touch; and such the condition of sensation in the adult. If we lay our hand upon a table, we become conscious, on a little reflection, that we do not feel the table, but merely that part of our skin which the table touches; but, without this reflection, we confound the sensation of the part of the skin which has received the impression with the idea of the resistance, and we maintain boldly that we feel the table itself, which is not the case. If the hand be now moved over a greater extent of the table's surface, the idea of a larger object than the hand can cover is obtained. If, to encompass the resisting object, the hand require to be moved in different directions and planes, the idea of surfaces applied to each other in different directions is conceived, and thus the notion of an external solid body occupying space obtained.

Our perception by sensation of the muscular movements necessary for thus passing our hand over the different surfaces of an object, is the immediate source of our idea of the external body; for the first idea of a body having extension and occupying space arises in our mind from the sensation of our own corporeal extension. This consciousness of our own corporeal existence is the standard by which we estimate in our sense of touch the extension of all resisting bodies. The question, whether the idea of space is originally innate in our sensorium, and influences all our perceptions, or whether it is the result of experience, may be here passed over: we shall return to it in discussing the physiology of the mental faculties. Thus much only is certain, that even though the idea of space did not originally exist as an obscure faculty

in the sensorium, which is afterwards called into action and applied when sensations begin to be perceived, it would assuredly be obtained by experience in the first acts of the sense of touch.

The obscure conceptions of a percipient body opposed to the external world, and itself occupying space, concerning the attribute of extension, or corporeal existence of external things, already exist, therefore, and have acquired some degree of lucidity and certainty before birth, at which time the sense of vision comes into action. The sensations of vision, in consequence of this, become soon intelligible; and the ideas already obtained through the means of the sense of touch are readily applied to their interpretation.

It is exceedingly difficult, if not quite impossible, to form a conception in any degree probable of the mode in which the child judges of the first impressions made upon the retina, and to decide whether it regards the image in its eye as a part of its own body, or as something external. The image cannot at all events be regarded as identical with the percipient "subject," or "self;" for, like pain and everything that is felt, it is an object opposed to this "self" of the child; but whether, as an object, it be looked upon as a part of the living body, or as something external and removed from it, is not so easily decided. It has been frequently asserted to be a peculiar property of the sense of vision that the sensation perceived by it does not, as in the sense of touch, appear to occupy the seat of its production,—that the retina does not perceive any sensations in itself; and that the sensation becomes an object of perception, not in the retina, but far distant from it. This cannot, however, be asserted thus absolutely; for the appearance of darkness before the eyes when closed, which is the sensation of the repose and unexcited state of the retina, seems to us to exist only in front of the eyes,—that is, in the situation of the sentient organ,—and neither behind us, nor at the sides, nor in the distance. And this dark field of vision of the closed eyes is the same frame, the same *tabula rasa*, in which, when the eyes are opened, all the images of visible forms appear as the results of the affection of determinate parts of the retina.

If the ideas of external objects, as the causes of sensation, had not already been gained by means of the sense of touch, the first use of the sense of vision would be attended with the same process as we have described to accompany the first acts of touch. The affections of the retina would be objects to the "conscious self" of the child; but whether they belonged to the living body, or were external to it, would not be evident. The child is, however, born already furnished with obscure ideas of objects external to its own body,—with ideas of their real existence as causes of sensations; and sensation and the idea of the external object of perception are already confounded in its sensorium. The

next steps of the process, as far as they can be imagined with probability, will be these :

The images of objects are formed in the retina in one surface, just as the retina is extended in that form. They will appear to the mind as depicted on a surface, and will excite no idea of proximity or distance, or of the actual occupation of space. However soon the child may recognise the images as things exterior to itself, they still appear to it to occupy one plane, to be all at the same distance from it : it catches at the most distant, as at the nearest object,—it grasps at the moon. The boy born blind, to whom Cheselden restored sight by operation, saw all objects as if they lay in one plane, although in him the ideas of the corporeal world obtained through the sense of touch were completely developed. It seemed to him as if the objects “touched his eyes as what he felt did his skin.”

The images of external bodies will be distinguished from the image of one's own body, which presents itself with them in the field of vision in the following manner. A part of our body throws an image, like external bodies, upon our retina. The part of our body thus visible with external objects, varies in size according to our position ; it may be a large or a small portion of the trunk, or of the limbs : the part of the head of which an image can be formed in the retina is very small, such as the sides or tip of the nose, the eyebrows when depressed, and sometimes also the lips. This image of our own body occupies, in nearly all pictures on our retina, regularly some determinate space in the upper, middle, or lower part of the field of vision ; it remains constant while the other images are continually changing.

The image of its own body being constant in its position, will in this way be soon distinguished by the child from those images which change their place when the body or eyes of the child are moved. From the movements, also, of this image of a part of its own body, the child will soon still more certainly conceive the idea of its possessing a body distinct from the absolutely external bodies ; for these movements of the image in the retina will be observed to correspond to real movements of its body determined by the will. With the visual perceptions of its body will become connected perceptions of touch. The child, touching another part of its body with its hand, will see this act performed by the image in the retina ; the image of its hand will touch the image of the other part of its body. In this way certain ideas become so inseparably connected with the sensations of vision, that not only does the image, which consists essentially merely in an affection of aliquot parts of our retina, seem to be external to, and removed to a distance from us, but the sensations come to be regarded as perfectly identical with the objects themselves, notwithstanding their difference of size.

Even the superficial expansion of the field of vision is soon converted by the imagination into a space extending in all directions; for, with every movement of our body, with every step forwards, the forms of the images undergo a change, the remote become near, and the near objects present other surfaces to our view. This change in the images depicted on our retina during the locomotion of our body, must convey to the mind the idea of our moving in space between the different images,—of our advancing through the midst of them; for, during this locomotion, the image of our own body in the field of vision becomes constantly associated with new images of external objects, and the locomotion is the cause of this displacement of the images.

From the foregoing considerations, we conclude that it is owing to the combined action of the mind and the nerves, and not to the action of the sense alone, which would merely perceive the changes produced in itself, that the sensation really seated in the nerve seems to us to be something exterior to the body.

X. The mind not only perceives the sensations and interprets them according to ideas previously obtained, but it has a direct influence upon them, imparting to them intensity. This influence of the mind, in the case of the senses which have the power of distinguishing the property of extension in objects, may be confined to definite parts of the sentient organ; in the sense gifted with the power of distinguishing with delicacy intervals of time, it may be confined to particular acts of sensation. It also has the power of giving to one sense a predominant activity.

The attention cannot be directed to many impressions at the same time: in proportion as coetaneous impressions on the senses become numerous, the sensations diminish in intensity, or the mind receives one only with distinctness; while the others are only obscurely, or not at all perceived. If the attention be withdrawn from the nerves of sense, and engaged in intellectual contemplation, deep speculations, or an intense passion, the sensations of the nerves make no impression upon the mind; they are not perceived,—that is to say, they are not communicated to the conscious “self,” or with so little intensity, that the mind is at the moment, on account of being quite preoccupied by some other idea, unable to retain the impression, or only recollects it some time after, when the equilibrium of the sensorium is restored, and it is freed from the preponderating influence of the idea which had occupied it. The acuteness which individual senses acquire when others are quite inactive, is therefore readily intelligible; the attention is no longer divided between the several senses, but is wholly engaged in the analysis of the sensations of one.

The blind man acquires such an extraordinary acuteness of touch, as to distinguish with facility the minute elevations on the surface of money, for example; sometimes, indeed, he is able to discriminate

between the corpus or grain of one colouring matter and that of another.

By an effort of the mind, however, the detail of a single sensation may be analysed. Since the mind is not capable of directing an equally accurate attention to every part of the cutaneous surface excited to sensation, an acute perception of the state of every part can be attained only by the mind being rapidly directed from the nervous fibres of one part to those of another. By this influence of the mind, an extraordinary degree of troublesome acuteness and permanence may be given to a slight itching sensation at any point of the skin of the face, while it ceases spontaneously when forgotten. The same influence of the mind is evinced in the sense of vision. If we endeavoured to direct our attention to the whole field of vision at the same time, we should see nothing distinctly, but our mental activity is directed first to this, then to that part, and analyses the detail of the sensation, the part to which the mind is directed being perceived with more distinctness than the rest of the same sensation. This does not arise from the middle of the retina, at which the sensibility is greatest, being turned towards the different parts of the object in succession; for, while the position of the axes of the eyes remains the same, we can by a mental effort render the perception of side objects more vivid than they were previously. Without changing the direction of the axis of vision, we can observe in succession the separate elements of a compound mathematical figure, which we are regarding, more accurately than the rest of the figure, which for the time we disregard. A polygonal figure, divided in its interior into different parts by lines, produces a different impression, according as the attention is directed to this or that part of the whole: a single triangle in the figure may wholly occupy our attention; at the next moment the attention may be transferred to another figure intersecting the triangle, which, though it existed before, was not observed while the mind was directed to the triangle. The same process takes place in examining architectural ornaments, as roses and arabesques; and the charm which these figures possess, consists in great part in their exciting a vivid action of the attention on different parts of the objects so as to cause them even to present to us an appearance of life. We ordinarily see with both eyes simultaneously when their power of vision is equal; but the mental influence is able to render predominant in intensity the visual impression of one eye, as we shall hereafter prove by experiment; and it may be distinctly demonstrated that, in seeing with both eyes, although under ordinary circumstances we are unconscious of it, a striving for predominance of the sensation takes place between them, and that the sensation perceived is quite different according to the relative intensity of their actions. The experiment of looking upon a sheet of white paper through two differently coloured glasses at the same time, may

serve as an illustration for the present. The impressions of blue and yellow, for example, are found in such an experiment not to mingle readily; at one moment the blue, at another the yellow is predominant. Sometimes blue nebulous spots are seen upon the yellow field; at other times, yellow spots of varying magnitude upon the blue field: sometimes one colour alone prevails, and has absorbed the other; sometimes the reverse is seen. The appearance of one colour in spots upon a ground of the other colour, shows indeed that the attention can be directed at the same time to one part of one retina, and to other parts of the other retina.

The influence of mental action upon the sense of hearing, which is not, like the senses of sight and touch, capable of the perception of corporeal extension in space, but has the most vivid perception of the succession of intervals of time in relation to impressions, is of another kind. The discriminating power of the organ of hearing, as to place, amounts at the most to the capability of determining whether the sound be heard with the one or the other ear, or by which it is heard most acutely; and then, when different words are addressed to the respective ears, the attention may be directed more to one impression than to the other. The influence of the attention, however, in distinguishing feeble sounds is highly remarkable: usually we do not perceive the more feeble tones of strings and other musical instruments; but, by attention, we cause their impression, as well as that of the slightest noise, upon the sensorium to become vivid. Still more remarkable is the faculty we possess of distinguishing by attention each of the many tones simultaneously emitted by an orchestra, and even of following the weaker tones of one instrument apart from the other sounds, of which the impressions are then less vividly perceived.

In concluding this introduction to the physiology of the senses, the question naturally presents itself: Is the number of the senses limited? may not some animals be endowed with other senses besides those which we possess? The error into which Spallanzani fell, in ascribing a peculiar sense to bats on account of their expertness of flight along the surface of walls when they could not see them, is well known. Many persons again have ascribed to animals a peculiar sense by reason of their foreknowledge of the changes of weather. Since the state of the atmospheric pressure, the quantity of watery vapour in the atmosphere, temperature, and electricity, have so marked an influence on the animal economy of our own bodies, that we are sensible of changes which they undergo, the possibility of such and even greater influences on animals may very well be conceived; but even great dependence on the state of the atmosphere with reference to sensation does not require a new sense.

On the contrary, the state of the atmosphere may be perceived by its influence on the whole nervous system, and particularly through the sensations of the nerves which are most numerous, and most exposed to the atmosphere, namely, the nerves of touch or common sensation. The supposed existence of a special sense for the perception of electricity in some animals is, *à priori*, not admissible; for electricity acts, as we have already shown, upon all the senses, exciting in each the sensations peculiar to it.

The essential attribute of a new sense is, not the perception of external objects or influences which ordinarily do not act upon the senses, but that external causes should excite in it a new and peculiar kind of sensation different from all the sensations of our five senses. Such peculiar kind of sensation will depend on the powers of the nervous system; and the possibility of the possession of such a faculty by some animals cannot, *à priori*, be denied: no facts, however, are known which establish the existence of such a new mode of sensation, and it is, in fact, quite impossible to have any experience of the nature of a sensation in any other beings than ourselves.

Some physiologists have regarded the internal sensations of the sense of touch by which we are made acquainted with the different states of our body, as something different from that sense, and have ranked the conscious perception of the different parts of our frame (*Gemeingefühl*, *cœnæsthesis*, or common feeling,) almost on a level with the other senses. This is an error; for the sensations here alluded to are of the same nature as those of the skin which are excited from without, only that in many organs they are more undefined and obscure. Moreover, it is indifferent whether a sense be excited to action from within, or from without; in no sense do we perceive any essential difference between the sensations thus produced. The designation, "sense of touch," expresses certainly a special relation of that sense to the external world; but the act of "touch" merely renders manifest the energies of this sense, which everywhere resides in the same nerves—the mixed cerebral and spinal nerves with double roots. Something analogous to the act of touch is observed in the other senses; it is an action of the sense voluntarily directed; and in the same way there is a voluntary hearing (listening), seeing (looking), tasting, and smelling.*

* The general treatises on the physiology of the senses are: *Le Cat*, *Traité des Sens*. Amst. 1744.—Elliot, *Observations on Vision and Hearing*. London, 1780. (*Über die Sinne*. Leipz. 1785.)—Steinbuch, *Beiträge zur Physiologie der Sinne*. Nürnberg, 1811.—Tourtual, *Die Sinne des Menschen*. Münster, 1827.

SECTION I.

Of Vision.

CHAPTER I.

OF THE PHYSICAL CONDITIONS NECESSARY FOR THE FORMATION OF
LUMINOUS IMAGES.*a. Of the possible forms of organs of vision.*

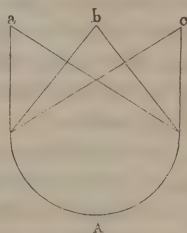
FROM the facts stated in the introduction to the physiology of the senses we have learnt that light and colour are sensations of the optic nerve and retina, and that the appearance of darkness before the eyes is the sensation proper to the state of repose, or unexcited condition of the retina. The sensations of light and colour are produced, in the midst of this darkness, wherever aliquot parts of the retina are excited by any internal stimulus, such as the blood, or by an external stimulus, such as mechanical pressure, electricity, &c. The seat of the sensation varies with the part of the retina acted on by the stimulus. The luminous spectrum produced by pressing upon one side of the closed eye is always seen upon the opposite side; and those produced by exerting pressure upon the upper or lower part of the retina are also seen at the opposite points of the field of vision. If the pressure is made by means of a small body, such as, for example, the blunt point of any instrument, and the parts of the retina affected by it consequently of limited extent, the luminous image is also small. If, on the contrary, the pressure be made over a greater extent at the angle of the eye with the edge of some body, the image produced has a corresponding extent. These images are not defined, on account of the pressure upon the eye-ball through the eye-lids and coats of the eye being necessarily diffused to a certain distance around the space which the pressing body itself would act upon. If, however, it were possible to confine the pressure accurately to determinate portions of the retina, we should doubtless be able to produce perfectly defined images by mechanical means. The physical imponderable principle which has received the name of light, because the luminous affections of the retina are usually caused by it, produces, when the whole of that nervous expansion is uniformly affected by it, the sensation of a diffused light occupying the whole field of vision, in place of the darkness seen before the eyes when the retina is not excited. But if this well-adapted and salutary stimulus of the retina acts only on definite parts of the retina, luminous images are formed at those parts, and the shadows of these images are the inter-

vening parts of the retina which are not stimulated to the sensation of light, and consequently retain the sensation of darkness, as when the eyes are closed. It is thus that we are enabled to see bodies, which either themselves radiate the principle called light,—luminous bodies, or, being impermeable by that principle, reflect it when they receive it from other bodies, and so direct it into the sentient eye. The sensation of light is then produced at a determinate part of the eye, and we think to see the body, which, however, merely reflects into the eye the principle capable of exciting the sensation of light, which it has itself received from elsewhere.

But that the light should produce in the retina luminous impressions or images of the objects from which it comes, it is necessary that the light emitted or reflected from determinate parts of the external objects should stimulate corresponding parts only of the retina; this requires the concurrence of certain physical conditions. Light radiates from a luminous body, in all directions, when the media offer no impediment to its transmission. A luminous point will therefore illuminate all parts of a surface opposed to it, and not merely one single point: in the exposed surface of the retina consequently the luminous point would excite the sensation of light in every part and not in one point only; and the same applies to all points from which light is radiated towards the retina. For example, if A, (fig. 60,) were the concave surface of the retina, red light emitted from the point *a*, colourless light from the point *b*, and yellow light from the point *c*, would each respectively illuminate every part of that surface, and the whole retina would consequently see red, white, and yellow light; that is to say, every point of it would be at the same time excited to sensation by three kinds of light, and the impression would necessarily not correspond to the differently coloured points *a*, *b*, and *c*, but would be a mixed impression of three different lights, of which neither would be distinguished separately. The same would be the result if the retina were convex anteriorly, as in insects and crustacea. A retina, therefore, without any optical apparatus placed in front of it to separate the light of different objects, would see nothing distinctly, but would merely perceive the general impression of daylight, and distinguish it from the night.

We see, therefore, that for the production of a luminous image in the eye, corresponding to the bodies emitting or reflecting the light, it is necessary that there should be apparatus to cause the light from the separate points *a*, *b*, and *c*, to act only upon separate points of the

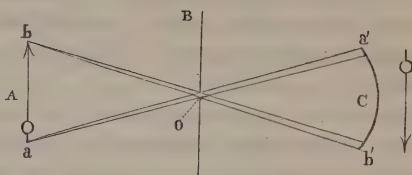
Fig. 60.



retina in the same order, and to prevent the light from different points of the external objects from acting on one point of the retina. There are three modes in which this can be effected, and nature has made use of two of these in the construction of eyes for distinct vision.*

1. Let A, (fig. 61,) be the luminous body, C the retina, B an opaque screen intercepting the light, except at the point *o*, where there is an opening. Through this opening the retina can alone receive light, and will consequently be in the

Fig. 61.



greater part of its extent quite darkened. In such a case the luminous rays from *a*, passing through the opening *o*, will fall on the retina at *a'* only, those from *b* at *b'* only, and every point of the object between *a* and *b* will be represented at special points of the retina between *a* and *b'*. *a* and *b* in the body A, are mathematical points; *a'* and *b'* in the illuminated retina are small spots, which will be larger, and the image consequently less distinct, in proportion as the opening *o* is larger. The smaller the opening *o*, the more defined will be the image, but it will be proportionally fainter, for the smaller will be the cone of light which passes from each point of the body A through the opening.† Nature has made no use of this means of forming images; probably because the result obtained is too inconsiderable, and because intensity of light at each point cannot be attained without simultaneous loss of distinctness.

2. The second mode of separating the rays of light so as to form an image upon the retina, to which I first directed attention in 1826,‡ is the following:—In front of the retina, and perpendicularly to its surface, are arranged side by side in immense numbers transparent cones which allow the passage of that light only to the retina which comes in the direction of their axis; while all the light which enters them laterally, and therefore must fall obliquely upon their walls, is absorbed by the pigment which invests them. Let A, (fig. 62,) represent the retina, which has a convex spherical surface, in the direction of the radii of which the transparent cones B B, are arranged. Those rays

* See J. Müller, *Vergleichende Physiologie des Gesichtssinnes*. Leipz. 1826, p. 307.

† For further observations on this mode of forming images see Dr. Roget's *Animal and Vegetable Physiology*, London, 1834, vol. ii. p. 451; and Kunzek, *Die Lehre vom Lichte*, Lemberg, 1836, p. 28.

‡ In my treatise on the physiology of vision, just referred to.

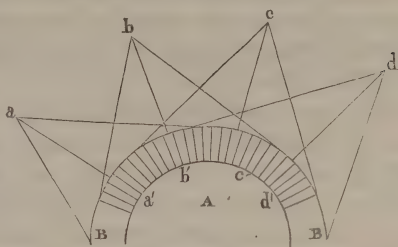
only of the light issuing from the points *a*, *b*, *c*, and *d*, will be able to reach the retina, which have the direction of the radii of the convexity. Thus the point *a*, although it illuminates the whole surface of the eye, will throw its image only at one point, *a'*, of the retina; the point *b*, its image at *b'* only; and so on.

All the rest of the light from these points, falling obliquely upon the surface of the eye, is excluded.

It is evident that the distinctness of the image must be greater in proportion to the number of the transparent cones arranged like radii upon the surface of the retina; and that, if there were a thousand of them, a thousand portions of the field of vision would be depicted in the image; and that, if their number were ten thousand, the distinctness of the image would be ten times greater. This arrangement of parts, which might be conceived as a possible form of visual organ, I have found really to exist in the compound eyes of all insects and crustacea. Such an organ of vision must, of course, be spherical, or a segment of a sphere. If its circumference approach the form of a plane surface, the exterior cones—those nearest to the margin of the eye—will necessarily be less divergent, and will correspond to a small portion only of the external world. In proportion, however, as the convexity of the eye, and the portion of a sphere which it forms, is larger, the extent of the field of vision will increase.

An image formed by several thousand separate points, of which each corresponds to a distinct field of vision in the external world, will resemble a piece of mosaic work; and a better idea cannot be conceived of the image of external objects which will be depicted on the retina of beings endowed with such organs of vision, than by comparing it with perfect work of that kind. A disadvantage which attaches to such an organ of vision is, that the quantity of light transmitted from one point of an object through the transparent cones must be extremely small. It appears, however, as we may observe in the evening when daylight is departing, that, for the mere discernment of objects even by the human eye, a very slight intensity of light is sufficient,—a light extremely feeble compared with that to which the eye is exposed during bright daylight; and even in our eye nature has been at more pains to moderate the quantity of light than to admit all that could enter. The smallest possible pupil is in a bright day adequate for vision.

Fig. 62.

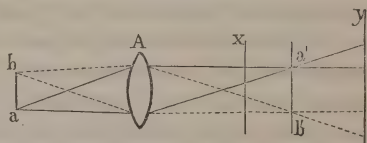


This kind of optical apparatus may be called the mosaic dioptric instrument, in contradistinction to the concentrating collective organ.

3. In the forms of apparatus hitherto described, the light, issuing from the different points of the external body, was kept isolated and confined to different points of the receiving organ by separating and excluding the rays which would interfere with this object; but the same end may be attained with more perfect definition and greater intensity of light by collecting together again into one point the different diverging rays emitted by each point of the external body. Here, however, it is, of course, requisite that the organ destined to receive the image should be situated exactly at that distance at which the rays are again collected to a point,—that is to say, at the apex of the cone of light. In the other forms of optical instrument, this condition was not necessary; here it is absolute. If, for example, we suppose the transparent body

A, (fig. 63,) to have the power of collecting the light issuing from the point a , and illuminating the whole surface of A to a point a' on its opposite side, and all the light issuing from b to the point b' , and in like manner of resembling all

Fig. 63.



the rays from different points between a and b , to corresponding points between a' and b' , the most perfect image of $a b$ will necessarily be formed at $a' b'$, and will be seen distinctly if the expansion of the optic nerve be situated at $a' b'$; while, if the expansion of the nerve be either in front or behind $a' b'$,—for instance, at x , or y ,—the image will be very imperfect; for, in that case the light from the point a will not be represented by a similar point, but will be dispersed over a considerable space, and so also will the light from each point of the object.

The bodies capable of collecting the rays of light in this manner are the transparent refracting media, and the most perfect form for the purpose of the organ of vision is that of the lens, as we shall now proceed to show more particularly.

b. Of the physical conditions on which the formation of images by refracting media depends.

The importance of the theory of the refraction of light in explaining the function of vision in man and animals, whose organs of sight have refractive media as essential parts of the apparatus, requires that the principal laws of this theory should be kept in mind.*

* I have extracted the account of the general laws of refraction of light from the best treatises of optics; those of Porterfield, Priestley, Fischer, Biot, Kunzek, and Brandes. Porterfield's treatise, *On the Eye, the Manner and Phenomena of vision*, 2 vols. Edinb. 1759, contains much very important matter.

When rays of light pass from a vacuum into a transparent body, or from a rarer into a denser medium, if their direction be perpendicular to the surface of the medium which they enter, they continue their course in the same direction ; but, if they impinge upon the surface of a denser medium in a direction removed from the perpendicular, they are bent out of their former direction towards that of a line perpendicular to the surface of the medium.

Thus, if $A B$, (fig. 64,) be the surface of the denser medium, the ray of light $a b$, instead of being continued in the direction $b c$, will be bent towards the line of the perpendicular $d e$, so as to have the direction $b f$.

When, on the other hand, a ray of light passes obliquely from any transparent medium into a vacuum, or from a denser into a rarer body, it is bent from the perpendicular direction, and, instead of following the line $b c$, will take the direction $b g$.

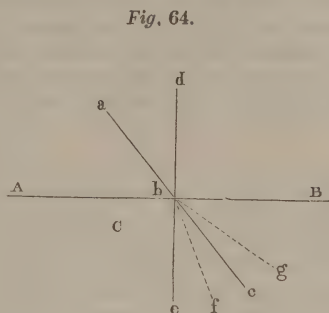
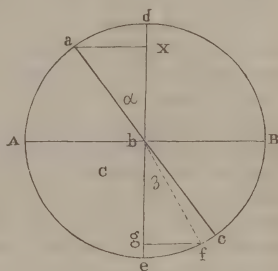


Fig. 64.

The incident ray, the refracted ray, and the perpendicular line, lie in the same plane. The law regulating the degree of refraction is the following :—The angle between the incident ray $a b$, (fig. 65,) and the perpendicular $d b$, is called the *angle of incidence* ;

the angle between the refracted ray $b f$, and the perpendicular $b e$, is called the *angle of refraction* ; the line $a x$ is the *sine* of the angle of incidence, and the line $g f$ the *sine* of the angle of refraction. Experience has taught that, if the two media remain the same, the relation between the sine of the angle of incidence α , and the sine of the angle of refraction β , will also remain the same, whatever be the inclination of the incident ray towards the surface of the refracting medium. The relation of two media in their refracting power will therefore be expressed by $\frac{\text{Sin. } \alpha.}{\text{Sin. } \beta.}$. The sines of the angles only,

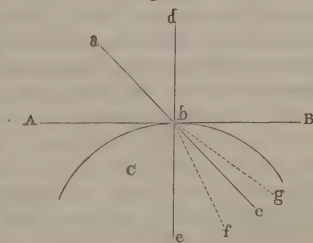
Fig. 65.



and not the angles themselves, have this uniform relation at every possible degree of inclination of the incident ray to the refracting medium : as long, however, as the angles remain small, as in the case of the central rays passing through lenses, there will be no great error in assuming the relation of the angles also to be constant.

Since a curved surface may be regarded as composed of an infinite number of plane surfaces, the tangent $A B$, (fig. 66,) of the point of incidence b , of a ray of light $a b$, falling upon the curved surface of a refracting substance, may be taken as the refracting surface, and the perpendicular, $d e$, of the tangent, will be the line towards which the ray will be bent so as to follow the direction $b f$, if the refracting medium be the denser, or from which it will be

Fig. 66.

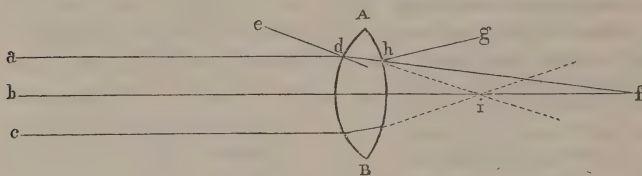


bent to the direction bg , if the medium which causes the refraction be rarer than that which the ray has previously traversed.

A knowledge of the laws of refraction of light by spherical lenses is important in relation to the study of the function of vision ; for such lenses are, under certain circumstances, capable of reuniting the rays of light issuing from a luminous point into one point, so as to form an image of that point.

If parallel rays of light, or rays of light issuing from a luminous point at a very great distance, impinge upon a plane refracting surface in an oblique direction, they are refracted, but their parallel relation to each other is not altered ; but, if such parallel rays fall upon a lens with a spherical surface, they are made to converge.

Fig. 67.

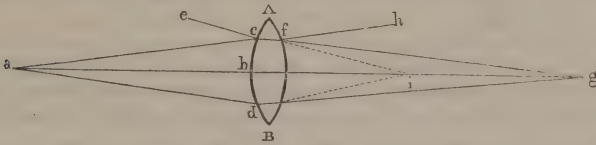


a , b , and c , (fig. 67.) are parallel rays of light ; the ray b coincides with the axis of the lens $A B$, and passes through it without suffering refraction ; but the other rays fall obliquely upon its surface, and issue from it obliquely with regard to its opposite surface, and are consequently refracted : the ray a is bent towards the perpendicular ed , of the incident surface, and passes through the lens in the direction df ; but at its exit, where it re-enters the rarer medium, it is again refracted and bent away from the perpendicular, hg , of the point of surface at which it issues, taking the direction hi , so as to approach still more rapidly the ray $b f$. If the rays a and c be equally distant from the ray b , which is coincident with the axis of the lens, the ray c will be refracted in precisely the same manner as the ray a ; so that both will, after their exit from the lens, intersect the ray b at some one point, i , where consequently all the three rays will be collected together ; but beyond this point they will diverge. Now, inasmuch as what applies to the rays a , c , will also apply to all parallel rays which are equally distant from the ray b , and impinge together with this upon the lens, all these rays will intersect each other at a common point i , which is called the focus. The distance of the focus of parallel rays from the lens depends on the refracting power of the substance composing the lens, and on the degree of convexity of its surfaces ; this focus will of course be, *cæteris paribus*, nearer to the lens the greater the convexity of its two surfaces.

If the incident rays issue from a body situated in the focus of the lens, they will be so refracted by it as to have a parallel course after their exit from it. It follows from this and the preceding law, that, if the rays come from a point further distant from the lens than its principal focus or the focus of parallel rays, but yet not so far distant that the rays may be regarded as parallel, they can neither be concentrated to a point at the principal focus, nor be rendered parallel. On the contrary, such rays will necessarily intersect each other at a point between the principal focus and infinite distance ; and, the nearer the luminous point from which they issued is to the focus of the lens, the further distant will the point of their reunion or intersection be behind the lens, and the more will they approach the parallel direction ; while, the further the luminous point is distant from the principal focus, the less will be the distance of the point to which the rays are made to converge, until at length, the distance of the luminous point

being such that the incident rays are essentially parallel, the point of their intersection becomes coincident with the principal focal point of the lens.

Fig. 68.



a, (fig. 68,) is the luminous point further distant from the lens *AB* than its principal focus; *a b* is a ray coincident with the axis of the lens, which it traverses therefore without undergoing refraction; but the ray *a c* is refracted twice, namely, at the anterior and at the posterior surface of the lens, being at the anterior surface bent towards the perpendicular, *ec*, of the tangent of the point of incidence, so as to receive the direction *c g*, and at the posterior surface bent away from the perpendicular, *f g*, to the direction *f i*. If the rays *a c*, and *a d*, impinge on the lens at equal distances from the point *b*, the ray *a d* will be refracted in exactly the same manner, and to the same degree, as the ray *a c*, and both will intersect the central ray at the same point, *i*. All rays emitted from the point *a*, which are equally distant with *a c*, and *a d*, from the central ray *a b*, will likewise be assembled at the point *i*: *a c d* may therefore be regarded as the periphery of a cone, which periphery is formed by luminous rays all converging to the point *i*. The distance of the point *i* from the lens is called the focal distance for diverging rays, which must not be confounded with the focal distance for parallel rays, or the principal focus. Diverging rays always come to a focus at a point further distant from the lens than the focus of parallel rays, and are more and more distant the nearer the luminous point from which the incident rays diverge is to the lens.

The distance of the focal point at which the luminous rays are collected from the lens, is dependent on three conditions: 1, on the refracting power of the lens in relation to the medium from which the rays enter the lens ($n:1$); 2, on the degree of convexity of the two surfaces of the lens, which are expressed by the length of the radii of the spheres of which they form part; 3, on the distance of the object from which the rays issue.

These three conditions being known, the focal distance of the image can be calculated for every distance of the object. The algebraic formula for this calculation is:

$$\frac{n-1}{f} + \frac{n-1}{g} = \frac{1}{a} + \frac{1}{x}.$$

$\frac{1}{f}$ expresses the refracting power of the lens, or the relation of the angle of incidence to the angle of refraction, which, for glass receiving rays of light from air, is $\frac{3}{2}$. $n-1$, therefore, for air and glass would be $\frac{3}{2}-1$. f and g are the radii of the convexities of the lens; a is the distance of the luminous point from the lens, and x is the desired focal distance of the image. If, for example, the medium be air, and the lens be of glass, and if the radii of the lens be 10 and 12 lines, and the distance of the luminous point from the lens 100 lines, the equation will be as follows:

$$\frac{\frac{3}{2}-1}{10} + \frac{\frac{3}{2}-1}{12} = \frac{1}{100} + \frac{1}{x}, \text{ or } \frac{3}{2} - 1 \left(\frac{1}{10} + \frac{1}{12} \right) = \frac{1}{100} + \frac{1}{x}.$$

The distance of the focus for parallel rays may also be found by the formula $\frac{n-1}{f} + \frac{n-1}{g} = \frac{1}{a} + \frac{1}{x}$. The distance of the luminous point from which parallel

rays proceed being considered as infinite, $\frac{1}{a}$ here equals 0; hence the formula may be stated thus, $\frac{n-1}{f} + \frac{n-1}{g} = \frac{1}{a}$; or, if α be employed to designate more especially the focal distance for diverging rays, the formula for finding the focus of parallel rays may be, $\frac{n-1}{f} + \frac{n-1}{g} = \frac{1}{p}$.

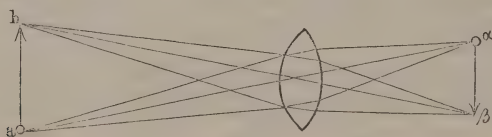
By combining the formula for finding the focal point of diverging rays with that for the focal point of parallel rays, a yet simpler fundamental formula for the solution of these optical problems is obtained; for, since the first half of the equation is in both instances the same, it follows that $\frac{1}{p} = \frac{1}{a} + \frac{1}{\alpha}$. Here p is the focal distance for parallel rays, a the distance of the luminous point, and α the focal distance of the image from diverging rays; hence the focal distance of the lens for parallel rays, and the distance of the luminous point, or object, being known, the focal distance of the image may easily be found. The equation will be, $\alpha = \frac{a p}{a - p}$.

The focal distance of the image of any luminous point is, therefore, found by multiplying the distance of the object from the lens by the focal distance for parallel rays, and dividing the product by the difference between them.*

If the surface which receives the image be not placed at the focal distance, the rays from each luminous point will, of course, fall upon it, not in a point, but dispersed over a larger surface, which is the section of a cone of light. Whether the opaque surface be placed in front or behind the focal point, the effect will be the same: in the one case, the rays of the cone of light will be intercepted before they have been collected to a point; in the second case, they will not strike the surface until they are diverging again in the form of a cone after having intersected each other.

Hitherto the refrangant power of lenses has been considered only in relation to rays issuing from a single luminous point; but if the object have a certain extent of surface, and the points radiating the light from it lie in a plane perpendicular to the line of the axis of the lens, the images of those points will also lie in the reverse order in a

Fig. 69.



similar plane. If $a b$, (fig. 69,) be the object, the cone of light issuing from a being refracted by the lens will be concentrated to a point again at α , the cone of light from b will be brought to a focus at β , and those from the intermediate points of the object in corresponding order. The image of the object is inverted,—the part

* For further details of this calculation, I refer to Fischer's *Mechanischer Naturlehre*, ii. 213; and to Kunzek's *Lehre vom Lichte*, Lemberg, 1836, 115.

[Rules for finding the focus of parallel, converging, and diverging rays, for lenses of glass in the air, by simple numerical calculation, are given by Dr. Brewster in his *Treatise on Optics*, p. 39. See also Sir J. Herschell's *Treatise on Light*, in the *Encyclop. Metropol.* § ix.]

which was above is below, that which was to the right is on the left side; but the relative position of the individual parts remains exactly the same. The middle rays of the cones of light α , and β , like the central ray of a luminous point lying in the line of the axis of the lens, are scarcely or not at all altered in direction. The other rays of the cone of light converge after refraction towards the middle ray; the image of the luminous point falls in the line of this ray, which consequently determines the position of the image of each luminous point, and the middle rays of the cones of light from the different points determine also the size of the image.

The points towards which the rays from the luminous points of the object, not coincident with the axis of the lens, are refracted to a focus, may be found by calculation; and it is ascertained that if such luminous points, though not in the line of the axis, yet be near it, so that the rays issuing from them and falling upon the lens do not form large angles with its axis, the different points of the image will fall in a plane parallel with the object.

Gregory* observed that the image of an object perpendicular to the axis of a lens of which the surfaces formed parts of spheres was not straight, but bent so as to appear concave towards the lens; and that, to form a straight image, the surfaces of the lens must have the form of the section of a cone (as an ellipse or hyperbole). Priestley admits this; but remarks that the error thence resulting is imperceptible, because the surfaces of the lens are very small parts of a sphere. Kaestner, however, adds that, if the aberration of the rays from the focus be disregarded,—that is, if the angles be regarded as proportional to their sines,—the most exact calculation will discover no curvature in the image of a plane figure.† That the plane of the image is parallel to the plane of the object, when the latter is perpendicular to the axis of the lens, is a matter of experience; and for an image of small extent, the mathematical proof of the axiom is not difficult, and is given with the mathematical calculations in extended works on physics.‡

Optical centre of lenses.—Since the two surfaces of a lens near the central point of these surfaces are parallel, or as good as parallel, rays which pass obliquely through the middle of the axis of the lens will not, after their transit, vary much from their previous direction, provided the points of incidence and exit lie within the parallel part of the two surfaces. Their refraction will be the same as that of rays passing obliquely through a glass plate with two parallel surfaces. The ray at its exit will be bent from the perpendicular to the same degree as it was bent towards it on entering the glass; it maintains, therefore, the same direction. Hence it is, that the middle ray of a cone of light passing with a moderate obliquity through the centre of the axis of a lens, is to be regarded as unchanged in its direction, and that its direction is to be regarded as determining that of the image. The point through which the rays must pass in order not to be refracted from their original direction, where the two surfaces of the lens are of unequal convexity, is not exactly the middle of the axis of the lens, but some point, either in front or behind that middle point, with which it is coincident only when the convexity of the two surfaces is equal. The knowledge of the optical centre of the lens is important for the better understanding of the theory of vision; I shall give here the mode of determining its situation, as stated by Fischer. § Let n (fig. 70) be the centre of the sphere, of which the anterior surface of the lens is a portion, and m the centre of the posterior surface. a is a given point of the anterior surface, and an consequently the radius of this surface. Let the radius of the

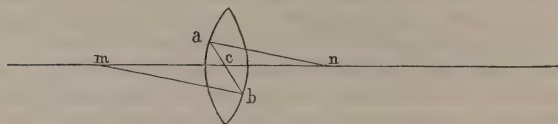
* Priestley's History of Light and Colours.

† Kaestner has given an example of such a calculation in the second volume of the Deutsche Schriften der Götting. Gesellschaft der Wissenschaften.

‡ See Kunzek, Lehre vom Lichte, 120.

§ Loc. cit. p. 217.

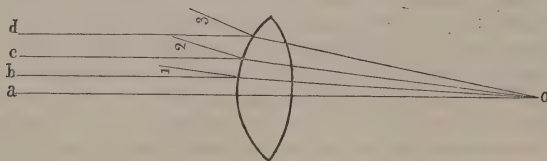
Fig. 70.



posterior surface, mb , be parallel with an . The point c of the axis of the lens, at which the line ab intersects it, is the optical centre; for, since an and mb are parallel, the angles nab and mba will be equal. If ab be a ray of light, the angle which this ray makes with the perpendicular an will be equal to the angle which it makes with the perpendicular mb . The angle of incidence of the ray entering the glass from the air bears the same relation to the angle of refraction, nab , as the angle of refraction of the ray leaving the glass to the angle of incidence mba ; consequently the angle of incidence of the ray entering the lens is equal to the angle of refraction of the ray leaving the lens, and hence the direction of the ray after its transit must be parallel to that of the incident ray, and the ray must be regarded as unrefracted. In a double convex lens, with unequally convex surfaces, the optical centre will lie nearer to the more convex surface.

Spherical aberration of lenses.—Hitherto we have considered principally the refraction of the rays which traverse the central portion of the lens; we must now direct our attention to those which pass through its circumference, and to their relation to the focal point. Whatever be the form of a spherical plano-convex or bi-convex lens, it is a constant law that those parallel rays which enter it at an equal distance from its axis are concentrated to the same point; for their angles of incidence and of refraction are equal. In the same manner, in a cone of light, of which the axis is coincident with the axis of the lens, all those rays striking the lens in a circle, and at an equal distance from the axis of the lens, will be concentrated again to one point. But what course do the other rays of the cone take? Are they also brought to the same focus? or have they another focal point? To bring the parallel rays a, b, c, d , (fig. 71,) to the focus o , the refraction of these rays must increase in

Fig. 71.



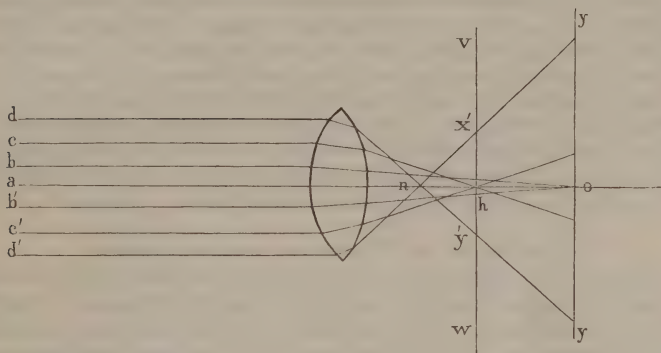
proportion as they are further distant from the line of the axis of the lens. This condition is afforded by media with convex surfaces, for in them the angles of incidence, 1, 2, 3, become greater in proportion as the rays, b, c, d , are further removed from the axis a . To condense parallel rays to a focus, it is therefore necessary that the surface of the refracting media be convex.

The question now comes, however, in what ratio must the angles of refraction of the parallel rays increase from the axis of the lens to its circumference, in order that they shall meet in a focus? or, in other words, what kind of curve must the surfaces of the lens have? Experience and calculation have shown that the object cannot be completely attained by means of lenses with spherical curves; and that the forms of

the surface necessary to concentrate the rays to a perfectly defined focus differ from that of the segment of a sphere, the only form which can be given to the surfaces of lenses by grinding. With such spherical surfaces the refraction of the rays increases too rapidly towards the circumference; and the rays most distant from the axis of the lens are consequently not brought to the same focus as the central rays. This is called "aberration from sphericity," or "spherical aberration." The focus for each circle of rays from the axis to the margin of the lens is different, becoming nearer to the lens the more remote the rays are from the centre.

I am not acquainted with any mathematical demonstration of this fact which would be readily intelligible, and shall therefore content myself with an empirical statement of it.* d, c, b, a, b', c', d' , (fig. 72,) are parallel rays. The rays $b b'$ traverse the

Fig. 72.



lens at the same short distance from its axis a ; and, the refraction being there considerable, they intersect the line of the axis at the point, o , furthest removed from the lens. The rays c, c' , which pass through the lens at a greater distance from its axis, are brought to a focus at h ; the rays d, d' , which are nearest to the circumference, intersect each other at n . If an opaque surface to receive the image be placed at o , there will be seen, not merely the bright focus of the central rays, but also a halo produced by all the other rays, which come to a focus, not at o , but at h, n , and other points of the axis $a o$; and the diameter of this halo will be $y y$. If the opaque surface be placed at h , the focus of the rays c, c' will be seen with a halo $x' y'$, and so on.

If the rays d, c, b, a, b', c', d' , in place of being parallel, were the base of a cone of light emitted from a point at a definite distance, they would still not be collected to a point by a lens with spherical surfaces; and on an opaque surface placed to receive them would be seen the focus of some of the rays surrounded by a halo formed by the others. The halo will, of course, be most considerable when the rays fall at the same time upon the centre and on the circumference of the lens, whether the image be received by a surface at o or by one at h ; for then, with the focus of the one set of rays, there will be received the others not brought to a focus. If, on the contrary, all the rays which pass through the circumference of the lens can be excluded while the passage for the central rays is left free, the opaque surface placed at o will receive the

* For the mathematical discussion of the question, Gehler, *Physikal. Wörterbuch*, vi. 1. 396, [and Sir J. Herschell's treatise on *Light*,] may be consulted.

focus of the central rays as a definite image, without any halo produced by rays refracted by the border of the lens. This object can be attained by covering the peripheral portion of the lens with a ring-shaped screen, or *diaphragm*. The image will be defined also if the light be allowed to pass through the circumference of the lens only, and not through its centre, for then the halo formed by the central rays around the focus of the marginal rays will be avoided. But the latter mode of avoiding the effects of aberration is not employed in optical instruments, because the aberration is greatest in the case of the rays refracted by the circumference of the lens. All optical instruments, however, require diaphragms to enable the lenses to give definite images.

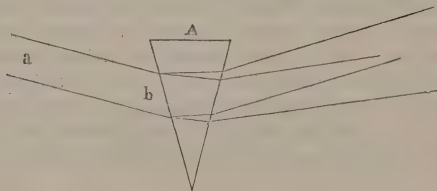
If the opening in the diaphragm be very small, new phenomena, resulting from the rays being bent by the edge of the diaphragm, arise, and interfere in a marked degree with the distinctness of the image.

The aberration from sphericity may be diminished to a very great extent by altering the relation of the curves of the two spherical surfaces. The slightest degree of aberration, according to Herschell, is produced when the radius of the posterior surface of the lens is from six to seven times as great as that of the anterior surface. If two thin lenses be combined, the relation between the radii of their surfaces may be made such that spherical aberration is wholly avoided. Increasing density of the lens towards its centre also must diminish aberration; for, by such a medium, the focal distance of the central rays is shortened, and approximated to that of the peripheral rays. Lenses which produce no spherical aberration are called "aplanatic."

*c. Of the physical conditions for the production of colours.**

1. *Dioptric colours.*—*Newton's theory of colours.*—By refraction, light is not merely bent out of its original direction, but, under certain circumstances, is rendered coloured. Coloured borders, indeed, are seen to surround the images produced by lenses. The phenomena of the production of colours is, however, most remarkable when prisms are used to refract the light. If a beam of the sun's light, *a*, *b*, (fig. 73.)

Fig. 73.

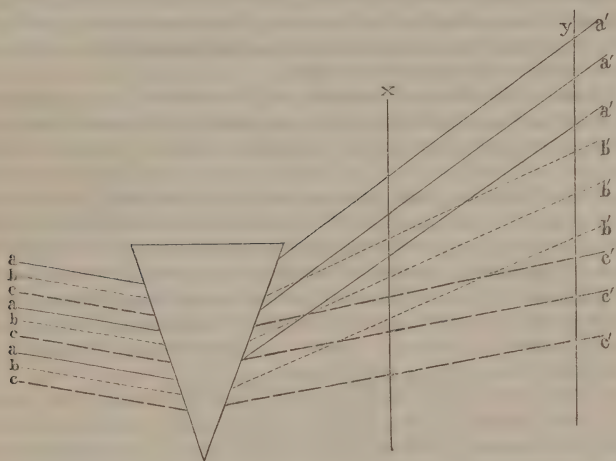


composed of parallel rays, fall obliquely upon the prism *A*, it will be refracted twice; namely, by its anterior and by its posterior surface; but, instead of the rays continuing parallel in their new course, the beam is spread out, and, when received upon an opaque surface, presents the colours of the rainbow. To observe these colours, it is not necessary to throw the light into a dark room through an opening in the window-shutter; the phenomena can be seen in open daylight, if the light of the sun after it has

* The works which may be consulted on this subject are,—Newton's *Optics*; Goethe's *Farbenlehre*; Brandes, in Gehler's *Physik. Wörterb. art. Farben*; Fischer's *Mechanischer Naturlehre*; and Pfaff über *Newton- und Goethe'sche Farbenlehre*. The three treatises last named are referred to more especially, as containing critiques on Goethe's theory of colours.

passed through the prism be received upon some opaque surface ; the colours, however, are much more vivid, and the borders of the image much more defined, in a dark room. The spectrum produced by the beam of light refracted by the prism, in place of being round and colourless, is elongated, with straight lateral borders and rounded extremities, and presents in succession the colours violet, blue, green, yellow, orange, and red. According to the laws of the simple refraction of light, the rays of light passing through the prism should receive a new direction, but ought to remain parallel. Inasmuch, however, as the spectrum is elongated, it is evident that the rays of light, while they have lost their parallelism, have undergone an unequal refraction. This fact suggested to Sir I. Newton his theory of colours. From the action of the prism on light, he concluded that in the sunbeam different elements or rays must be contained which have different degrees of refrangibility, and that those only which are homogeneous, or have the same refrangibility, follow the same direction after passing through the prism. If, for example, in the beam of parallel rays, *a, c* (fig. 74), the rays

Fig. 74.



a, a, a have equal refrangibility, the rays *b, b, b* also equal refrangibility, but a different degree of refrangibility from the rays *a, a, a*, and the rays *c, c, c*, again, agree in refrangibility among themselves, but differ in that respect from the rays *a, a, a* and *b, b, b*, it will follow that after refraction all the rays *a', a', a'* will be parallel, but that the rays *b', b', b'*, though parallel among themselves, will have a different direction from the rays *a', a', a'*, and also from the rays *c', c', c'*, which again will be parallel amongst themselves, but neither with the rays *a'* nor the rays *b'*. The homogeneous rays *a', a', a'* will appear with the same colour, namely, violet ; the homogeneous rays *b', b', b'*, with the same colour, namely, blue ; and the homogeneous rays *c, c, c*, with the same colour, green ; and so other similar rays with the colours yellow, or orange, or red. Violet and red lie at the extremes of the spectrum ; the violet rays having the greatest, the red rays the least refrangibility. The colours are not seen, however, unless the spectrum is received upon an opaque surface at the proper distance from the prism ; for instance, at *y*, where the diverging rays of different kinds, *a', b', c'*, are no longer mingled with each other. If the surface which receives the spectrum is placed nearer to the prism, for instance at *x*, the dissimilar rays *a', b', c'*, are mingled in the middle of the image, which in such case appears white,

while the upper and lower extremity only are coloured ; and, the nearer to the prism the rays are intercepted, the less will those of different kinds be separated from each other ; the larger will be the white middle portion of the spectrum, and the smaller the coloured borders.

These facts and considerations lead to the inference that a white body receives, and reflects upon the eye at the same time, all the different kinds of luminous rays ; that colour, on the contrary, results from the impression upon the retina being produced by one kind of rays ; in other words, that white light is composed of the different coloured rays which combined give the sensation of the white, but which, on account of their different refrangibility, may be separated from each other by refragent media.

This inference is confirmed by the fact that the different coloured lights may be combined again so as to produce white light.

1. If the spectrum is received behind the prism by a condensing glass, the colours are combined at a certain point into a beam of uniform white light, although the coloured rays beyond this point again continue their separate course.

2. The same thing is effected by allowing the sun's light to pass through two prisms of equal refracting angle, placed in opposite directions. In this case the one prism, by refracting the rays in the opposite direction, neutralizes the action of the other, and the spectrum is consequently white.

3. Or the coloured lights may be collected to a point by means of a concave mirror, upon which they are received obliquely, so as to be reflected downwards upon a white surface, which then presents a colourless bright spot in place of a coloured prismatic spectrum.

The prismatic colours are produced, though not in such intensity, by the refraction of light by means of lenses instead of the prism ; the images of objects formed by lenses have a border of prismatic colours. A lens may be regarded as a prism of which the refracting angle increases towards the margin, and in which the decomposition of the light is effected, not in one direction only from above downwards or from below upwards, as in the prism, but in all directions from the centre towards the periphery. The coloured margins are the more evident the further distant the point where the image is formed is from its proper focal distance.

The use of the word "rays" in the statement of Newton's theory of colours has induced in some persons the incorrect belief that, according to this theory, each ray of white light is composed of several rays of coloured light, — its elements as it were. But, to have an accurate conception of the results deducible from Sir I. Newton's discoveries, it is necessary to refer to the organ of vision, which has a share in the production of the phenomena of colours and light. The surface of the retina is, we know, composed, like mosaic-work, of the ends of an extraordinary number of nervous fibres, and each papilla of this mosaic-work represents the smallest elementary portion of the organ of vision which is capable of sensation. While the different-coloured lights fall upon the composite surface of the retina in such a way that each of the elementary portions receives one simple kind of light only, *a* receiving blue, *b* yellow, and *c* red light ; so long will their impressions of colours be perceived as existing distinct from each other. But if the same minute portions of the retina are acted on at the same time by all the principal colours, so that the same papillæ of the retina receive at the same time the impressions proper for the sensations of yellow, red, and blue, none of these colours will be distinguished, but from the mixed impression the sensation of white will result. This is all that can be concluded from Newton's experiments. The simultaneous impression of all the colours on the same parts of the retina produces the sensation of white.

Sir I. Newton admitted, without sufficient reason, the existence of seven dioptric colours resulting from the decomposition of white light by refraction, and this arbitrary

view was too long adopted; it ought to have been corrected before the time of T. Mayer and Goethe. There are three primitive colours only, yellow, blue, and red; the others may be explained by the mixture of these. Between the yellow and blue of the spectrum lies green, which results from their admixture; between blue and red lies violet; and between red and yellow, orange. If red and blue light fall upon the same elementary portion of the retina, neither of those colours will be perceived, but in place of them violet; and so of the other colours producing mixed impressions. Hence the combination of a mixed colour with a simple homogeneous colour is equivalent to the combination of all the three simple colours, because the mixed colour must always contain the two other simple colours; for instance, two-thirds orange and one-third blue is equivalent to one-third blue, one-third red, and one-third yellow, since the union of the two latter colours constitutes two-thirds orange.

If the prismatic orange and the prismatic blue be by a special contrivance made to fall together upon the same surface, the impression will be white, as when produced by the union of all the three primary colours; in the same way white may be produced by the union of red with green (which contains blue and yellow), or of yellow with violet (which contains blue and red). A mixed prismatic colour, and a simple homogeneous colour, which produce white when combined, are said to be "complementary." Green and red are complementary of each other; so, likewise, are violet and yellow, and blue and orange. Absolute darkness, or the black colour, is the mere negative result of certain parts of the retina, or its entire surface, being in the state of repose or freedom from excitement. If the impression of colours unmixed with white be feeble, they necessarily appear more or less dark. If the impression of white light be sufficiently weak, the retina has the sensation of "grey;" as when a grey colour is produced by the admixture of white and black. The grey colour may, however, result from the mixture of different colouring matters; red, yellow, and blue pigments, when mixed, produce a grey colour. Two pigments will yield a grey, if one be a simple homogeneous colour and the other a mixed colour, that is, a colour composed of two simple colours which with the other simple colour would afford the three primary colours of the spectrum.

Thus, red and green yield grey.
 yellow .. violet . . . —
 orange .. blue . . . —

Two colours, which together yield a grey colour, are therefore also called "complementary."

In figure 75 the three simple colours are placed at the angles of an equilateral triangle, which are connected together by means of a circle; the mixed colours are placed intermediate between the corresponding simple or homogeneous colours; and the complementary colours, of which the pigments when mixed would constitute a grey, and of which the prismatic spectra would together produce a white light, will be found to be placed in each case opposite to each other, but connected by a line passing through the centre of the circle. This

Fig. 75.

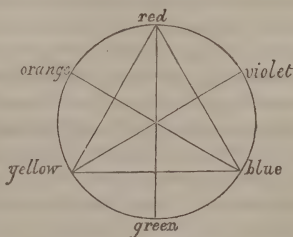


figure also is useful in showing the further shades of colour which are complementary of each other. If the circle be supposed to contain every transition of colour between the six marked down, those which, when united, yield a white or grey colour, will always be found directly opposite to each other; thus, for example, the intermediate

tint between orange and red is "complementary" to the middle tint between green and blue.

If we divide the surface of a circular disk into three equal portions, separated by three radii (sectors), and paint each with one of the three simple colours, these colours will disappear when the disk is made to revolve so rapidly that the images of the different coloured sectors change their place on the retina before the effect of the previous impression is lost, and the disk appears grey. The revolving disk will also appear grey if its surface present two complementary colours only in a definite proportion as to the space they occupy; for example, a mixed colour occupying two-thirds of the disk, and a simple colour occupying one-third. But if one of the colours is in too great proportion, it will be seen when the disk is made to revolve, and the grey will not be perfect. Two simple homogeneous colours, without their third complementary colour, never produce a grey when mixed, but merely intermediate or mixed tints; for instance, green results from the mixture of blue and yellow, violet from the mixture of blue and red, orange from the mixture of red and yellow.

These facts have been regarded as proofs of the incorrectness of Newton's theory, according to which all the primary colours, and therefore the complementary colours also, should when mixed produce white, and not grey. But, if Newton's theory be correct, the result can scarcely be other than it is; for the pigments are so dull, and absorb so much light, that grey is necessarily produced instead of white. A coloured body owes its colour, according to Newton's theory, to its absorbing one or more of the simple colours of the sun's light, and its reflecting the rest; which constitutes its colour. The impression produced by the different coloured images of a revolving disk cannot be white, for a white disk reflects all the light which strikes it, while the coloured one reflects merely a portion. Hence the united impressions of the different colours upon the same spot of the retina must produce a feeble sensation of white, or a grey which is lighter or darker according to the brightness or dulness of the pigments. But if we concentrate the brilliant colours of the prismatic spectrum to a focus, we obtain a pure white image; and the same is the case, as Von Grotthuss* has shown, when two complementary dioptric colours are made to combine.

Lastly, it must be remarked, that the intermediate tints produced by the union of two prismatic colours can be resolved by means of the prism into their original elementary colours, but that the intermediate colours of the true prismatic spectrum cannot be decomposed any further by the prism. This seems to prove that more than three primary colours exist in the sun's light, and that it probably contains an infinite number of rays differing in refrangibility. That the intermediate colours of the prismatic spectrum, and those produced artificially by the mixture of simple colours, should make the same impression on the retina, exciting the sensation of green, for example, while they are so different with respect to their susceptibility of decomposition by the prism, may be explained according to the undulatory theory, by supposing that undulations of the rapidity of the green rays of the prismatic spectrum produce the same impression upon the retina as undulations of yellow and blue rays of different rapidity striking the same part of the retina at the same time. The rapidity of the undulations of the green rays is, indeed, intermediate between that of the yellow and that of the blue rays; but the rapidity of the undulations of the violet rays is greater than that of the undulations either of the blue or of the red rays.

[Sir D. Brewster, by the use of media capable of absorbing certain of the coloured rays of light, has been enabled not only to explain why the orange and green rays of the solar spectrum cannot be decomposed by the prism,—a circumstance apparently

* Schweigger's Journ. iii. 158.

incompatible with the hypothesis of three primitive colours, but also to demonstrate more exactly than had hitherto been done the true constitution of the spectrum. The colours of transparent media depend on their absorbing some of the colours of white light, and transmitting others. Thus blue glass, the colour of which is not the pure blue of the prismatic spectrum, absorbs all those rays which with the rays producing its compound blue colour would form white light. If the solar spectrum be viewed through a plate of such blue glass of a certain thickness, the middle of the red space will disappear, and with it the whole of the orange, a great part of the green, a considerable part of the blue, a little of the indigo, and very little of the violet. The yellow space, which has not been much absorbed, will have increased in breadth, occupying part of the space formerly covered by the orange on one side, and part of the space formerly covered by the green on the other. Hence it follows that the blue glass has absorbed the red light, which, when mixed with the yellow light, constituted orange; and also the blue light, which, mixed with the yellow, constituted the part of the green space next to the yellow. The orange and green rays, therefore, though they cannot be decomposed by prismatic refraction, can be decomposed by absorption, and actually consist each of two different-coloured rays, possessing the same degree of refrangibility. Difference of colour is, therefore, not a test of difference of refrangibility. By analysing the spectrum in this way, by means of various coloured media, Sir D. Brewster has arrived at the conclusion, that red, yellow, and blue light exist at every point of the solar spectrum; and, consequently, that as a certain portion of red, yellow, and blue constitute white light, every point of the spectrum may be considered to consist of white light mixed with the predominating colour or colours.]

The theory of colours proposed by Newton is not essentially affected by the adoption either of the undulation or the emission theory of light; for impressions which, according to the latter theory, are produced by rays of coloured light of different nature, may also be due to differences in the undulations, and to the different rapidity of motion of the different coloured lights which suffer unequal refraction in passing through refracting media.

The objections brought by Goethe against Newton's theory of colours are, in the main, founded on erroneous views. Goethe* and Seebeck† regard colour as resulting from the mixture of white and black, and ascribe to the different colours a quality of "darkness" (*σκιερόν*), by the different degrees of which they are distinguished, passing from white to black through the gradations of yellow, orange, red, violet, and blue, while green appears to be intermediate again between yellow and blue. This remark, though it has no influence in weakening the theory of colours proposed by Newton, is certainly correct, having been confirmed experimentally by the researches of Herschell, who ascertained the relative intensity of the different coloured rays by illuminating objects under the microscope by their means. The illuminating power was greatest in yellow and yellow-green, less in orange, still less in red, less again in blue, and least of all in violet (which, however, we should have expected to have been intermediate in illuminating power between red and blue). The brightness of the green rays was less also than that of the yellow-green. Another certain proof of the difference in brightness of the different coloured rays is afforded by the phenomena of ocular spectra. If, after gazing at the sun, the eyes are closed so as to exclude the light, the image of the sun appears at first as a luminous or white spectrum upon a dark ground; but it gradually passes through the series of colours to black,—that is to say, until it can be no longer distinguished from the dark field of vision; and the colours which it assumes are successively those intermediate between white and black in the order of their illuminating power or brightness, namely, yellow, orange, red, violet,

* Farbenlehre.

† Schweigger's Journ. i. 4.

and blue. If, on the other hand, after looking for some time at the sun, we turn our eyes towards a white surface, the image of the sun is seen at first as a black spectrum upon the white surface, and gradually passes through the different colours from the darkest to the lightest, and at last becomes quite white, so that it can no longer be distinguished from the white surface. But, although the remark of Goethe relative to the different degrees of darkness of the colours is correct, yet it affords no proof of the correctness of his main principle, that colour is the result of the mixture of light and darkness. Darkness is, as we have already remarked, nothing positive; it is merely the expression of repose of the retina, or of parts of it.

A mixture of white and black, whether by the impressions of the two upon the same parts of the retina being made to succeed each other very rapidly, as by means of a revolving disk, or by both being allowed to act at the same time upon the same points of the retina, never gives rise to any colours, but produces "grey;" which shows merely that the impression which causes the sensation of white is moderated, so that the sensation of grey results.

The fact of some semi-opaque media — as, white glass, or the air loaded with moisture, — causing light previously white to appear coloured when it has passed through them, was thought by Goethe to be a proof of the correctness of his theory of colours; but it is now known to result from certain media having the property of absorbing some of the component rays of white light while they allow the passage of others.

2. *Natural colours of bodies. — Pigments.* — The natural colour of bodies not themselves luminous, is due to the light which falls upon them, and is reflected by them towards our eyes; and in part also it depends on the affinity of the bodies for light, and for the different coloured rays, since they sometimes reflect all the coloured light; sometimes absorb it completely, becoming heated at the same time; sometimes partly reflect, and partly absorb it; while in other cases, again, they allow all the light to pass through them, or allow the transmission of some of the coloured rays, but absorb others. A white body is one which reflects all the different coloured rays simultaneously; a black body is one which appropriates all the different rays, and reflects none; while a coloured body is that which absorbs or transmits certain of the coloured rays of white light, and reflects the rest. A transparent colourless body transmits all the different coloured rays, as white or colourless light, reflecting only a very small part of each, so that no colour is produced. A transparent coloured body absorbs certain of the coloured rays, and transmits the remainder as coloured light. The dependence of the colour of opaque bodies upon the absorption or transmission of certain of the component coloured rays, and upon the reflection of others, may be proved by experiment.

Coloured bodies which ordinarily reflect the coloured ray α , when illuminated only by a simple coloured light which contains none of the rays α , are of course, no longer able to reflect these rays, and appear therefore perfectly colourless. A lamp-wick saturated with common salt, and burnt with alcohol, gives, as Brandes remarks, a homogeneous yellow light, in which all objects but those which are yellow appear devoid of colour. Most coloured lights are, however, not simple or homogeneous, and contain, besides the prevailing rays of one colour, white light.

Transparent coloured bodies sometimes appear of a different colour by reflected, from that which they have by transmitted light; in other instances, they appear of the same colour by reflected and by transmitted light. The same cloud may appear of a bluish colour by reflected, and of a yellow or orange tint by transmitted light. In the first case, we do not see the yellow and red rays which it allows to pass through it, but only the bluish rays which are reflected; in the second case, we see the transmitted rays, yellow and red, but not those which are reflected, — the blue. In this

way Brandes explains the blue and orange tints of the atmosphere under different circumstances. When the atmosphere is clear, it appears in the evening blue towards the east, where it reflects towards us the blue rays, while it transmits the yellow and red, which are therefore invisible to us; in the west it appears at the same time of a yellowish red colour, because it transmits thence the yellow and red rays to our eyes, while it reflects back the blue rays. In the same manner, bluish white glass, when held towards the light, appears of a fiery red colour. Other transparent bodies have the same colour both by reflected and by transmitted light; they reflect one portion of the coloured light a , and transmit another portion of the same light a , while they absorb completely the other coloured rays, b, c .*

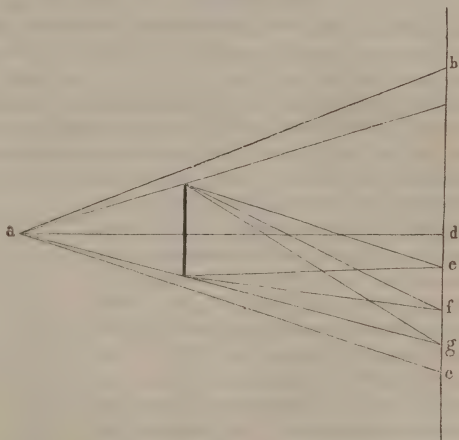
3. *Of the colours produced by "interference" of the rays.*—The stability of Newton's doctrine of colours is not affected by the phenomena which required for their explanation the principle of "interference," or the reciprocal influence of the luminous rays upon each other, discovered by Dr. Young. Since many of the phenomena of colours hitherto difficult of explanation owe their production to this principle, an exposition of the most important points of the theory will be necessary to complete our account of the physical laws of colours.

The property of the luminous rays discovered by Dr. Young is this:—Two rays coming from one point, and after passing through paths of slightly different length meeting again at a very small angle in one point, under some conditions increase each other's intensity; under others, destroy each other. This reciprocal influence of the rays of light is called "interference."

Fig. 76.

Admit into a dark room the cone of light $a b c$ (fig. 76).

At a short distance from the apex of the cone place a narrow strip of pasteboard, or wood. (This is made very broad in the figure, to render it more distinct.) Let $b c$ be a surface receiving the shadow. If the light issuing from a be homogeneous, — for instance, the red light of the prismatic spectrum, — there will be seen upon the surface, $b c$, instead of a simple shadow, a series of alternate red and dark lines. If the surface $b c$ be brought very near to the opaque body, the shadow will be defined

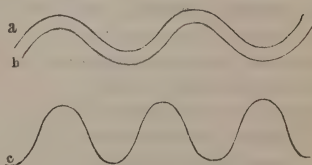


and free from the lines of coloured light; and, the further it is removed from it, the more evident will those lines become. The middle band d will be red. If the passage of the light be interrupted at one border of the card, so that it can no longer reach the surface $b c$ from that side, the coloured lines will cease to be visible; which proves that the phenomenon is due, not to the inflexion of the light at the margins of the card, but to the reciprocal action of the rays passing at the opposite borders on each other. It is, however, owing to the laws of inflexion, to which light is subject when it passes close to the edges of bodies, that the rays from the opposite sides meet on the surface $b c$.

* See Brandes, Gehler's Physik. Wörterbuch, art. Farben.

The rays passing the upper border of the card or pasteboard in the figure are inflected from their direction $a b$ towards the points g, f, e, d ; the inflexion affecting those rays most which are nearest to the edge of the card, and diminishing as their distance from it is greater, until at a certain distance they maintain their original direction $a b$. By this "inflexion" or "diffraction," rays which issued from the point a , and were diverging from each other, are again brought together. The rays which thus meet will in the middle of the shadow be of equal length; those meeting at all other points, as e, f, g , will be of unequal length. Now, since the image of the inflected rays emitted by the point a presents dark lines alternating with red lines, it follows that certain of the rays of red light inflected by the opposite borders of the opaque body have, by meeting at certain points of the surface $b c$, destroyed each other, causing these points to appear dark; while other rays of the red light have not destroyed each other, and cause the parts of the surface which they fall upon to appear red. The same phenomena may be produced, as Fresnel has shown, by reflecting the rays issuing from a luminous point by means of two mirrors in such a manner as to produce interference; reflexion doing here what was effected by inflexion in the experiment above described. The phenomenon of interference is easily explicable if the undulatory theory of light be adopted. The rays of red light which meet at the point d , are of equal length—have passed through an equal number of undulations, and at this point the red light is not lost; but the rays which meet at the points e, f, g , are of unequal length, and each has passed through a different number of undulations. All such rays of unequal length either add to one another's intensity, or destroy each other. The difference in length of the rays meeting at e may be greater or less than the length of one of the undulations of red light, each of which undulations consists of a condensed and a rarefied portion. If one ray have passed through one entire wave more than the other ray which meets it at e , the waves of two rays will, according to the laws of all undulations, increase each other's intensity, and not destroy each other; for the condensed portion of the wave of one ray will coincide with the condensed portion of the wave of the other ray, and the rarefied portion of the wave of one ray with the rarefied part of the wave of the other ray, or, in other words, the elevations and depressions of the one will coincide with the elevations and depressions of the other, as in fig. 77, a, b . The result of such a relation of the rays can only be an increase of intensity of the ray reflected from the surface $b c$ (fig. 76); the elevations and depressions of the waves or undulations becoming exaggerated (fig. 77, c). The effect will be the same when the difference in the length of the rays amounts to three, four, five, or six, entire undulations; for, in such cases, the elevations or depressions of the undulations of the two rays will always coincide.

Fig. 77.



If, on the contrary, one of the rays meeting at any point have passed through only half a wave more than the other ray, the rarefied portion or depression of the wave of one ray, a , will coincide with the condensed portion or elevation of the wave of the other ray b , as represented in fig. 78; and the elevation of one will neutralise the depression of the other, so that both will be destroyed, and the spot on which they fall will appear dark. If the difference in the length of the paths which the rays have traversed be less than an entire wave, but more than half a wave, the rays will interfere more or

Fig. 78.



less with each other, according to the amount of their difference in length. It may easily be perceived that these phenomena afford the means of calculating the size of the undulations of the different coloured rays. The relation of the dark and light lines in the image varies according to the kind of coloured light used in the experiment.

We have hitherto considered the case of the "interference," of rays of simple homogeneous light. If white light be used in the experiment, the peculiar phenomena of colours are produced, which it is our main object to explain. Instead of the alternate lines of black and a single colour, vivid stripes or fringes of the different homogeneous colours are seen. This is easily explained, on the same principle as the preceding experiment. The waves of each colour contained in white light have a different length; each of the simple homogeneous colours will consequently have its own separate coloured and black stripes, produced in the same way as when a simple colour is employed.

The theory of the production of colours by "interference" explains very readily the colours seen in thin plates of bodies with a fine laminated structure, and on very finely grooved surfaces. It is a fact well known, that light passing through a transparent body is reflected in part by its anterior and posterior surfaces. A ray falling perpendicularly upon a thin transparent lamina will be reflected in part by the anterior and in part by the posterior surface; the two parts of the ray meet again after reflection, and, if the difference in length of the paths which they have traversed is small enough, the appearance due to interference will be produced. The same is the case with rays falling obliquely upon such a body; for the ray reflected from the anterior surface will meet with part of some other ray reflected from the posterior surface of the lamina, and give rise to "interference." The colours seen on finely grooved surfaces are explained in the same manner. Of this nature, therefore, are the iridescent colours of laminæ of mica or glass, soap bubbles, mother-of-pearl, &c.*

In conclusion we give the table of the lengths and rate of the undulations in the rays of different coloured light, as calculated by Sir J. Herschell from the phenomena of interference.

<i>Colours of the Spectrum.</i>	<i>Length of an undulation in parts of an inch.</i>	<i>Number of undulations in an inch.</i>	<i>Number of undulations in a second.</i>
Extreme red . . .	0.0000266	37640	458,000000,000000
Red	0.0000256	39180	477,000000,000000
Intermediate . . .	0.0000246	40720	495,000000,000000
Orange	0.0000240	41610	506,000000,000000
Intermediate . . .	0.0000235	42510	517,000000,000000
Yellow	0.0000227	44000	535,000000,000000
Intermediate . . .	0.0000219	45600	555,000000,000000
Green	0.0000211	47460	577,000000,000000
Intermediate . . .	0.0000203	49320	600,000000,000000
Blue	0.0000196	51110	622,000000,000000
Intermediate . . .	0.0000189	52910	644,000000,000000
Indigo	0.0000185	54070	658,000000,000000
Intermediate . . .	0.0000181	55240	672,000000,000000
Violet	0.0000174	57490	699,000000,000000
Extreme violet . .	0.0000167	59750	727,000000,000000

* On the theory of "interference," see Weber, *Wellenlehre*, Brandes, loc. cit.; and, on the undulation theory of light, Gehler's *Physik. Wörterbuch*, art. Licht; [and Sir J. Herschell's *Treatise on Light*.]

CHAPTER II.

OF THE EYE AS AN OPTICAL INSTRUMENT.

1. *Optical structure of eyes.*

THE structure of eyes, regarded with reference to their function of the perception of light generally, and of distinguishing objects more particularly, presents three principal forms:—1. The simplest eyes or eye-dots of the Annelida and lower animals, which enjoy probably by means of their eyes merely the general perception of light, so as to distinguish, for example, day from night, or light places from dark. 2. The mosaic-like compound eyes of insects and Crustacea, furnished with transparent media calculated to insulate the rays of light coming from different objects, or from different parts of objects. 3. Eyes with transparent media for concentrating the rays to foci.

A. *The simplest eyes or eye-dots of the Annelida and other inferior animals.*—It can be distinctly demonstrated that the eyes of Insecta, Crustacea, and Mollusca have the apparatus necessary for separating the rays from different points of objects. The question is, whether the so-named eye-dots of the Annelida and other inferior animals have a similar provision, or whether these are wholly destitute of optical apparatus, possessing merely the faculty of distinguishing light from darkness, and day from night. The animals in which these eye-dots are met with will be enumerated at p. 1123. The *Hirudo medicinalis* has ten eyes, ranged in a semicircle at the anterior part of the head above the mouth. Weber describes them as being raised above the surface like warts, and as being prolonged as cylinders into the interior of the animal. The extremity of each is covered by a convex very transparent membrane, beneath which is a black lamina, and the lower portion of the cylinder is black. No pupil or transparent refracting media have been seen in these eyes, nor in the semilunar eyes of several Planariæ. I have examined the structure of the eye-dots in the Nereida. In the genus *Nereis* (Andouin and Edwards) there are four black eye-dots arranged in a quadrangle upon the surface of the head. They are not raised, but lie immediately beneath the epidermis of the head, are round posteriorly, towards the free surface flat, and consist of a cup-shaped black membrane, containing a round white opaque body which is prolonged into the optic nerve (see fig. 79). The four optic nerves enter the upper surface of the brain at separate points. The eyes of this animal are therefore destitute of optical apparatus. The light has access to the body contained within the choroid, for this presents a circular aperture on the side towards the light :

Fig. 79.*



* [Fig. 79.—A. Eye of *Nereis*, after Müller ; B. the choroid partially removed, showing the bulb of the optic nerve within.]

but the round body appears to be merely the papillar extremity of the optic nerve; for it is opaque, has the same aspect as the nerve with which it is distinctly continuous, and has a fine granular structure. The animal in which I examined these eyes had certainly been preserved in spirit; but the transparent organs in the eyes of insects, spiders, and snails, preserved in spirit, keep their natural appearance.* Rathke† has likewise observed the pupil-like opening of the choroid in *Nereis Dumerilli*; but he has also described a second form of the eye in the family of the *Nereida*, namely in the genus *Lycoris*, in which this pupil is absent, and the choroid of a nearly black colour surrounds the whole eye. In this form still less than in the former can we suppose that the eye has the power of distinguishing forms, or is capable of anything more than a mere vague discrimination of light from darkness by means of the rays of light which are able to penetrate through the covering of pigment. Rudolph Wagner,‡ who confirmed by his observation of fresh specimens of *Nereida* my description of the papillar enlargement of the optic nerve, and the absence of transparent optical apparatus, believed that he could distinguish, in young examples of the *Hirudo medicinalis* just escaped from the ovum, transparent parts in addition; namely, a bell-shaped vitreous body, with red granules of pigment loose upon its surface, and, in front of this, a portion like a lens. It is certain, however, that of the *Nereida* some have a pupil, but no internal transparent media, and that others have not even a pupil; and we are therefore justified in ascribing to these animals merely the faculty of distinguishing light from darkness.

The existence in a genus of *Nereida* of true organs of vision totally covered with pigment without any pupil, and the similarity of these organs to the eyes of other *Nereida* which have a pupil, render it probable, that even in other inferior animals the black or dark-coloured eye-dots, though destitute of pupil, are with justice regarded as having a relation to the perception of light.

One example only of eyes unprovided with optic refracting apparatus is known among the Vertebrata. In the *Myxine glutinosa* I found a small eye, not merely beneath the skin, but really beneath the muscles; though in the allied genus, *Bdellostoma*, the eye lies at the surface. The eye of the *Myxine glutinosa* has no lens; but contains merely a bulb-like body filling the whole eye, which bears more resemblance to the bulb of an optic nerve than to a vitreous body. The perception of light is still possible here, although the eye is still covered by the muscles; for we are able to see the light through the thickness of our fingers and entire bones. These animals, therefore, will have merely the power of distinguishing light from darkness, day from night.

* J. Müller, Ann. des Sc. Nat. t. xxii. p. 19.

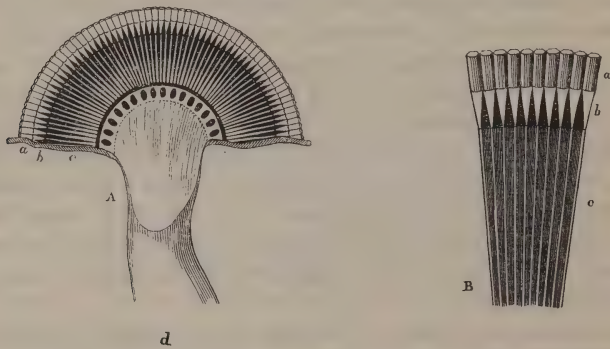
† De Bopyro et Nereide. Riga, 1837.

‡ Vergleichende Anatomie, i. p. 428.

B. *Compound eyes of Insecta and Crustacea with a mosaic-like structure.**

The compound eyes of insects and Crustacea are more or less considerable segments of spheres sessile and fixed in the insects; but, in the Decapoda and some other Crustacea, moveable upon pedicles. The optic nerve also swells out in these eyes into a large ball or segment of a sphere, from the surface of which thousands of primitive nervous fibres rise, and are directed like radii towards the surface of the organ. They do not, however, reach the transparent covering or cornea of the eye; on the contrary, as I have demonstrated, in all orders of insects, and also in the Crustacea, the ends of the fibres of the optic nerve and the cornea are separated by transparent cone-like bodies likewise arranged in a radiate manner against the inner surface of the cornea, with which their bases are united, while their apices are received upon the ends of

Fig. 80.†



the fibres of the nerve (fig. 80). The length of these cones is very different in the different genera: in general, namely in most Coleoptera (beetles) and Lepidoptera (butterflies), they are five or six times as long as they are broad; in rare instances they are very short,—thus in the flies among dipterous insects their length scarcely at all exceeds their breadth. In insects, and the decapod Crustacea, the cornea is composed of numerous portions like mosaic-work, each small portion or facet corresponding to one of the transparent cones connected with the fibres of the optic nerve. The facets of the cornea are hexagonal in insects; they have rarely this form in Crus-

* J. Müller, Physiologie des Gesichtsinnes; Leipz. 1826. Ann. des Sc. Nat. t. xvii. pp. 225. 365.—Continued observations in Meckel's Archiv. 1829; 38. 177.

† [Fig. 80.—A. Section of the eye of *Melolontha vulgaris*, after Strauss Durckheim. *a*, facets of the cornea; *b*, parts supposed by Strauss to be enlarged extremities of the nervous fibres, but by Müller shown to be transparent cones surrounded with pigment; *c*, the fibres of the optic nerve; *d*, the trunk of the optic nerve.—B. Portion of the eye of *Melolontha*, after Müller; *a*, prismatic segments or facets of cornea; *b*, transparent cone-like crystalline bodies; *c*, fibres of optic nerve.]

tacea, but in them are generally more nearly quadrangular, though the lines which divide them cannot here be right lines, in consequence of the surface of the eye being convex, but must be curves. In some instances, as in the *Lepidoptera* (butterflies), the facets are slightly convex, both externally and internally, that is, lens-shaped; generally, however, they are nearly plane, and indeed of considerable thickness, as in the *Orthoptera* and *Coleoptera*. The similarity of their anterior and posterior surfaces will not allow us to ascribe to the facets of the cornea any important influence in general upon the light: and in a great number of *Crustacea*, in the *Entomostraca* namely, according to my observations, they are wholly wanting, although the transparent cones remain; the surface of the cornea being in this case both externally and internally completely smooth. It is only where the cornea is thus smooth, and devoid of facets, that the bases of the cones which are ordinarily united with the facets of the cornea, are rounded. Between the transparent cones, and even between the fibres of the optic nerve, there is pigment, of which the colour is sometimes dark, at others light; it may be nearly black, dark violet, dark blue, purple, brown, brownish yellow, light yellow, or green. Sometimes, indeed, several layers of different colours lie one over the other. The pigment rises between the cones as far as the cornea, and in some instances even covers the anterior surface or base of the cones to such an extent as to leave only a central pupil to each cone; this pupil is particularly evident when the cones are very short, as in dipterous insects. In other instances the bases of the cones are quite free from the pigment, which extends no farther than the lines of separation between the facets of the cornea. In the eyes of the lower *Crustacea*, where the cornea is destitute of facets, the cone-shaped transparent bodies are in the greater part of their length imbedded in the pigment, while their larger rounded extremities project out of it, and are turned to the inner surface of the perfectly smooth cornea. The number of the facets of the cornea and of the cones varies very much; it is generally very great, amounting to several thousand,—for instance, twelve or twenty thousand in one eye; in rare instances, as in some entomostracous *Crustacea*, they are few in number. R. Wagner has investigated the exact mode of connection of the fibres of the optic nerve with the cones. In insects the fibre of the nerve is prolonged as a sheath over the sides of the cones; and, since the nervous fibres in the higher animals consist of a tube and contained matter, it is possible that this tube contributes chiefly to form the sheath of the cone.*

I have mentioned that according to my observations the eyes of many *Crustacea* have a cornea destitute of facets and transparent cones with

* On this point see Wiegman's *Archiv.* 1835. i. 372, and Müller's *Archiv.* 1836, 613.

rounded bases. This induced me several years ago* to divide the compound eyes into two principal classes. There is, however, a third modification of the structure of the compound eyes, which has been observed by Edwards, Burmeister, and myself, in several of the Crustacea. It is that where lenticular bodies exist between the cornea and the transparent cones. These lenses must concentrate the rays of light which fall upon them, and throw them towards the axis of the cones. M. Edwards† observed this structure in *Callianassa*, in many brachyurous decapods as *Cancer maculatus*, in *Amphitoe*, and in several of the *Edriophthalmida*. I saw with M. Edwards small lenses in the facets of the cornea of *Hyperia*. *Branchiopus paludosus* also has, according to Burmeister's observations, lenses with longitudinal axes of considerable length behind the facets of the cornea, and in front of the cones.‡ Some of these animals, as *Amphitoe*, and several *Edriophthalmida*, *Hyperia*, and *Branchiopus*, have two corneæ, of which the external is smooth, while the internal one is marked with facets, or has fenestræ behind which the lenses lie, as in *Branchiopus*. It appears then that the following may be set down as the modifications of compound eyes:—

1. Compound eyes with cornea divided into facets and transparent cones without lenses. Observed in insects and most decapodous Crustacea.

a. The cornea with simple facets.

b. The cornea with marked lens-like elevation of the internal surface of the facets. Ex. *Meloe*.

2. Compound eyes with cornea destitute of facets, and no lenses.

a. The transparent cone-shaped bodies rounded at their base. Observed in *Daphnia*, *Apus*, *Gammarus*, *Cyanus*, &c.

b. The bases of the cones united with the cornea. Ex. *Limulus*.

3. Compound eyes with lenses in front of the transparent cones.

a. The cornea divided into facets. Observed in *Callianassa* and several *Brachyura*, as *Cancer maculatus*.

b. Two corneæ; the external smooth, the internal divided into facets. Observed in *Amphitoe*, several *Edriophthalmida*, and in *Hyperia*.

c. Two corneæ; the external smooth, the internal with fenestræ. Ex. *Branchiopus*.

Allied to these compound eyes with lenses and cone-shaped vitreous bodies, is the fourth kind of compound eye pointed out by me as early as 1829.

4. Aggregates of simple eyes, of which each contains the essential parts of a simple eye, namely, lens and globular vitreous humour. This form is met with in several *Isopoda*, as *Cymothoe*; and in the *Myriapoda*,

* See Meckel's Archiv. 1829.

† Hist. Nat. d. Crustacées, t. i. p. 116. Paris 1834.

‡ Müller's Archiv. 1835, p. 529; and 1836, p. cii.

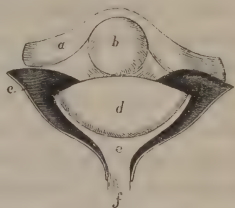
Julus. This is the transition form between mosaic-like compound eyes unprovided with concentrating apparatus, and the organ of vision with such apparatus.

*C. Simple eyes of Insecta, Arachnida, Crustacea, and Mollusca, provided with concentrative refracting media.**

a. Simple eyes with lens.

1. *Arachnida*.—The eyes of the *Arachnida* are constructed upon the principle of those of man and vertebrate animals generally. Behind the cornea is a spherical lens, and behind this a vitreous body. The black choroid forms a ring around the lens (fig. 81).[†] Usually the *Arachnida* have several of these eyes; the scorpion, for example, has two upon the upper surface of the head, and six of smaller size upon its margin: in the *Scorpio teter* (Mus. Entom. Berol.) from the Cape, and in the *Scorpio occitanus*, I found as many as ten eyes at the anterior margin of the head.[‡]

Fig. 81.†



2. *Crustacea*.—Eyes with concentrative refracting media or lenses are rare in *Crustacea*. Where they occur, they are given as accessory organs, the compound mosaic-like eyes being also present. They are here commonly called “simple eyes,” to distinguish them from the compound. Thus the *Limulus Polyphemus* has, in addition to the compound eyes, two “simple eyes.”

3. *Insecta*.—In this class the simple eyes with lenses occur both alone and associated with compound eyes. The former is the case in several apterous insects, as the *Scolopendra*, which has four eyes on each side of the head, the *Poduræ*, and parasitic *Aptera*. The larvæ of carnivorous *Coleoptera* also have simple without compound eyes; thus the larvæ of *Cicindela* and *Aristus* have two, the larvæ of the water-beetle, *Dytiscus*, twelve (six on each side). The larvæ of *Hymenoptera* are, for the most part, destitute of eyes; but the larvæ of bees have two simple eyes. The larvæ of *Lepidoptera* are ordinarily provided with several simple eyes on each side of the head. Some insects in the perfect state, as the *Orthoptera*, the *Hemiptera*, *Neuroptera*, *Hymenoptera*, and the families *Sphynx* and *Phalæna*, or crepuscular and nocturnal *Lepidoptera*, have from two to three simple eyes together with compound eyes.

* J. Müller, *Physiol. des Gesichts-sinnes*, p. 315.—Ann. d. Sc. Nat. t. xvii. p. 232.—Ann. d. Sc. Nat. t. xxii.—Meckel's Archiv. 1829, pp. 38 and 203.

† [Fig. 81.—Eye of scorpion, after Müller. *a.* cornea; *b.* lens; *c.* choroid; *d.* lenticular vitreous body; *e.* cup-shaped retina; *f.* optic nerve.]

‡ On the structure of the eyes of *Arachnida*, and the union of the characters of compound with those of simple eyes; see Brants, in the *Tydschrift voor natuurlyke geschiedenis*. 4. 1 and 2 Stück. p. 135.

According to my observations, the simple eyes of these insects have the same structure as those of the Arachnida. They certainly contain a spherical lens close behind the cornea, and probably a substance analogous to a vitreous humour. Sometimes these eyes are elongated transversely; one of the eyes of the *Scolopendra morsitans* has this form, as have also two of the circle of eyes on each side of the head of the larvæ of *Dytiscus marginalis*; in this case the lens also is oblong.

The function of the simple eyes of insects is probably confined to the perception of very near objects. This may be inferred partly from their existing principally in larvæ and apterous insects, and partly from several observations which I have made relative to the position of these simple eyes. In the genus *Empusa* the head is so prolonged over the middle inferior eye, that, in the locomotion of the animal, the nearest objects only can come within its range. In the *Locusta cornuta*, also, the same eye lies beneath the prolongation of the head. The same is the case in the genus *Truxalis*. In *Gryllus vittatus* (Fabr.) the simple eye lies beneath, just above the helmet, or *galea*: and it has the same position in most species of *Gryllus* with a conical head; for example, in the *Gryllus serrulatus* and *G. crenatus*. In the *Gryllus lithoxylon* (Klug) the middle simple eye lies entirely concealed in a furrow between the antennæ, so that its field of vision must be very small, and confined to very near objects. In *Acheta monstrosa* the simple eyes are scarcely perceptible, being seated on the radicle portion of the antennæ, and nearly included in the articulation of those organs with the head. In Orthoptera generally, also, the simple eyes are, in consequence of the depressed position of the head, directed downwards towards the surface upon which the insects are moving. In most Hymenoptera, on the other hand, the eyes are placed more posteriorly, as in *Malaxis*, *Cimbex*, *Tenthredo*, *Leucopsis*, *Sirex*, *Ichneumon*, *Chrysis*, *Lasius*, &c. From these facts, I consider myself justified in concluding that the simple eyes of insects are intended principally for myopic vision. The simple eyes bear a similar relation to the compound eyes, as the palpi to the antennæ. Both the antennæ and compound eyes are absent in the larvæ of insects.

4. *Mollusca*.—Organs of vision of similar structure to the simple eyes of Arachnida and insects are also possessed by many Mollusca, namely, by the whole order of Gasteropods. They contain a lens, and traces, more or less distinct, of a vitreous body.* These organs appear to the naked eye like black points, and are seated either at the extremity of the tentacles, upon a projection at the middle of their outer surface, or at their base. Those of the *Helix* are situated somewhat to the side of the extremity of the great tentacles. In their general structure they resemble the eyes of the higher animals, have a cup-shaped choroid

* J. Müller, Ann. d. Sc. Nat. xxii.

which forms a zone anteriorly, a lens and a vitreous humour, as was known to Swammerdam. The eye of the *Murex Tritonis* has, at least, one of the refracting media, a transparent body of considerable size and nearly round. With regard to the optic nerve of gasteropods, anatomists were formerly in error, mistaking for it the great nerve of the tentacle, which is the nerve of touch; the optic nerve is much more minute, and looks like a branch of that larger nerve, but may be traced backwards to the cerebral ganglion. The organ of vision in gasteropods appears to be adapted for the perception of the nearest objects only; for the *Helix pomatia* does not avoid an object placed near it until it is within two or three lines of the tentacle.

The eyes of cephalopod Mollusca contain all the essential parts of the organ of vision of the higher animals, even the iris and corpus ciliare.

b. Aggregates of simple eyes.—We may thus designate the organs of vision of some animals, which are produced by the aggregation of a great number of simple eyes into one mass, but in which each single eye either has the structure of the simple eyes of Arachnida and Mollusca, or is formed upon the model of the eyes of the higher animals. I met with such eyes in some insects and Crustacea, namely, in the genus *Julus* among insects [or Myriapoda]; and in some of the isopodous Crustacea, [German, Asseln], for instance, in *Cymothoa*. The surface of the organs of vision in these animals presents a number of convexities corresponding to the individual eyes. About as many as forty eyes may be united in one such aggregate organ. Behind each convex cornea is a roundish lens; and behind this a nearly spherical vitreous body, which is surrounded by retina and choroid. The aggregate forms the link between the simple eyes with refracting media for concentrating the rays of light and the compound mosaic-like eyes with lenses and conical transparent bodies.

D. The eye of man and vertebrate animals.—This is not the place to treat of the structure of the different parts of the eye, and to describe its general anatomy. It is our object here to refer merely to the principal structural relations important for the function of vision, and to the most essential differences presented by the eye in the different classes of vertebrata.

Appendages of the eyes.—The eye-lids.—The eye-lids may be entirely wanting, the skin passing in that case simply over the surface of the eye, as in many fishes and several Amphibia,—for example, in the Proteida and Pipa; or the skin forms eye-lids (palpebræ), which may be either single or double, or be united into a circular zone with a central opening, as in the chameleon. In addition to the ordinary eye-lids, there is seen in some animals the membrana nictitans, or third eye-lid, which exists in a rudimentary state even in Mammalia, is most fully developed

in birds and reptiles, and exists again in a less perfect form in fishes, namely, in several genera of the shark family. In birds this *membrana nictitans*, which is a translucent membrane, can be drawn from the inner side over the anterior surface of the eye by means of a peculiar muscular apparatus subject to the *nervus abducens*. The sharks in which this membrane exists are the genera *Carcharias* and *Galeus*, and several others allied to them; in the genera *Scyllium*, *Lamna*, *Selache*, *Alopias*, *Notidanus*, *Spinax*, *Centrina*, *Scymnus*, and many others it is wanting.

Of similar nature to the *membrana nictitans* is a spectacle-like transparent space in the inferior eye-lid of some lizards, as several of the *Scincoid* family, which can be drawn over the eye; and, while it corresponds to the cornea, does not prevent vision. The immoveable capsule in front of the eye in serpents is, on the contrary, quite a peculiar structure. The eye-lids are in other animals replaced by a transparent capsule lying in front of the eye, and continuous at its margin with the skin of which it is an attenuated prolongation. This capsule is composed of three laminæ: of an external one, which is a continuation of the epidermis, and is therefore cast off when the skin is shed; of a middle layer prolonged from the cutis; and of an internal layer, which corresponds to the *conjunctiva palpebrarum*, and, like it, is reflected at its circumference so as to be continuous with the *conjunctiva* covering the globe of the eye. Between this capsule and the anterior surface of the eye of serpents is a cavity into which the tears are poured, and whence they escape, as usual, through the lachrymal canal. The last-mentioned provision was first discovered in serpents by Cloquet: it exists even in those which have the eyes covered by a thick skin, as in *Amphisbænæ*, &c.; and I have also detected it in a mammiferous animal, *Spalax typhlus*, the eyes of which are covered by a thick hairy cutis, but have under this skin a cavity formed by *conjunctiva*. Lizards have generally eye-lids; but in one family, the Geckos, I have discovered the remarkable peculiarity that the eyes are covered by a transparent capsule, as in serpents.

The *lachrymal apparatus* is absent in cetaceous Mammalia, in Amphibia, and in fishes.

The tunics of the eye.—The *sclerotica* in many animals exhibits a tendency to be cartilaginous or bony. In birds, *Chelonia*, and lizards, the anterior part of the *sclerotica* immediately around the cornea contains a ring of osseous plates, of which the edges either lie one over the other in an imbricated manner, or are merely in apposition; and the *sclerotic* coat in fishes generally contains two large plates of cartilage.

The *choroid* is in animals divisible into two laminæ,—the external proper choroid, and the internal *membrana Ruyschiana*; in fishes the external lamina has generally a silvery lustre, while the internal is

covered with pigment. Between the two at the point of entrance of the optic nerve is situated the glandula choroidalis, a body of a horse-shoe shape which receives a large quantity of blood.* The *ciliary ligament* is in man and Mammalia of fibrous structure, but in birds appears to be muscular. The inner surface of the choroid is in all animals covered by the *membrana pigmenti*, which is composed of flattened cells, often of hexagonal form, containing the granules of pigment. In albinos these cells contain no pigment. In several animals it is normally deficient at certain parts of the eye, which then either are white, or have a metallic lustre, and are called the *Tapetum*. The tapetum at the posterior and external part of the eye in ruminant animals is covered with the cells of the pigment membrane, but the pigment itself is wanting. The metallic lustre and iridescent colour of the tapetum in these animals appears to be owing to the structure of the choroid producing "interference" of light, and not to the presence of any material colouring matter; they are therefore lost when the choroid is dried.† The perfectly white colour of the tapetum, which occupies an accurately defined triangular space at the bottom of the eye of carnivorous animals, is not destroyed by drying, and is due to a peculiar pigment. The smallest quantity of light entering the eye is reflected by the tapetum; and hence it is that the eyes of animals provided with this structure are luminous in a very faint light, though not in perfect darkness (see page 93).

The *corpus ciliare*, or *ciliary processes*, do not exist in fishes, with few exceptions; but a *falciform process* passes through a cleft in the retina, and attaches itself firmly to the margin of the lens, which is also held in its position by a small pear-shaped body (the *campanula Halleri*).

The *iris* is mobile in most animals, but in the osseous fishes is scarcely, if at all, so. In the horse, narwhale, lama, and rays, it presents at the upper border of the pupil a veil-like appendage. The *pupil* is sometimes round; sometimes elongated transversely, as in the Ruminantia; sometimes in the perpendicular direction, as in the cat family and the crocodile; sometimes triangular, as in the brown or fire toad, *Rana bombina*, &c.

The *pecten* or *marsupium*, is characteristic of birds; it is a pyramidal

* [On the structure of this body, see Mr. Owen's remarks in the third volume of the *Physiol. Series of the Catalogue of the Hunterian Museum*; and Mr. Wharton Jones's paper in the twenty-first volume of the *Med. Gazette*, p. 650.]

† [It has been shown by Hessenstein, Valentin (*Repertor.* 1837, p. 246), and Mr. H. J. Carter, (*Medical Gazette*, Jan. 5, 1839,) that the action of the tapetum of ruminant animals in decomposing light depends on its being formed of parallel waving fibres like those of tendon. The influence of these fibres in producing the iridescent colours is explicable on the principle of "interference," see page 1107.]

plicated process provided with pigment, which has its origin in the choroid coat, passes through an opening in the retina, at the bottom of the eye, into the middle of the vitreous humour in the direction of the margin of the lens; its situation is the posterior and external part of the cavity of the eye. Lizards have a trace of the pecten, and the processus falciformis of fishes is perhaps an analogous structure.

Transparent media of the eye.—The fibrous structure of the lens has been already described at page 396. [Fig. 82, A, represents the disposition of the fibres in the lens of Mammalia; fig. 82, B, shows the

Fig. 82, A.

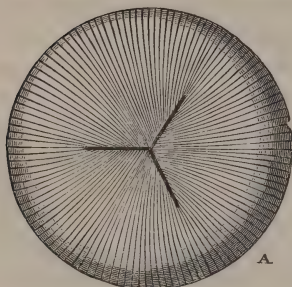
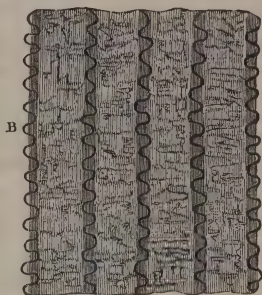


Fig. 82, B.



mode of union of the different fibres by their toothed margins.]* The arrangement of these toothed fibres is very different in the different classes and orders of animals.† The internal laminæ of the lens are always more firm than the external; in fishes the former have an extraordinary hardness, almost like that of horn. In aquatic animals the lens is always more convex than in those which live in the air; in fishes it is spherical, and in the cuttle-fish (*Sepia*) elongated in the direction of its axis. Convexity of the cornea would have been of no service in these animals, since the refracting power of the aqueous humour differs little from that of the water in which they live; though in animals living in the air the refraction produced by the cornea and aqueous humour is very great. Hence it was necessary that the refracting power should be provided in these aquatic animals by greater convexity of the lens. The anterior half of the lens in fishes projects through the pupil into the anterior chamber of the eye.

Optic nerve and Retina.—The most remarkable peculiarities of structure are presented by these parts. The optic nerve is always constituted of primitive nervous fibres, which are similar to those of the

* [Figs. 82, A and B, are copied from Sir D. Brewster's paper in the *Philos. Transact.* 1833.]

† Brewster, *Philos. Transact.* 1836.

brain, being very minute, much more so than those of other nerves. The nerve thus composed either presents a merely fibrous structure, as in man: or these fibres are arranged in particular situations, as at the chiasma, into laminæ, the laminæ of one nerve passing at this part between those of the other, as in birds, reptiles, and Amphibia: or, lastly, the whole optic nerve, in its course from the brain to the eye, is membranous; this structure, which Malpighi discovered in the sword-fish, appears to be characteristic of all fishes. When the sheath of the optic nerve in these animals is laid open, the optic nerve is seen, having the form of a membrane with free borders folded together like a curtain; and it would seem that the retina is formed simply by the unfolding of this membrane.* The retina in the eye of fishes has at least two corresponding free borders, being cleft and gaping from its anterior margin to the fundus of the eye.

The union of the two optic nerves soon after their origin, or the optic commissure or chiasma, next requires our attention. The varieties in structure with relation to this part may be stated as follow:—1. The structure which exists in osseous fishes. Here the two nerves are connected after their origin by a slender transverse commissure; and then form no chiasma, but simply decussate without their fibres mingling, the right nerve going to the left eye, and the left nerve to the right eye. 2. The structure proper to cartilaginous fishes. Here the nerves do not decussate as in osseous fishes, but are closely connected by a commissure, the internal structure of which is not known; this form approaches very nearly to the chiasma of the higher animals. 3. The chiasma of Amphibia, reptiles, and birds, which in external appearance is similar to that of Mammalia, but has an internal laminated structure; the laminæ of one optic nerve passing between those of the other nerve, like the crossed fingers of opposite hands. It is not yet known whether all the fibres of the two optic nerves decussate here, or whether a portion is continued to the eye of the same side as that of their root. 4. The chiasma of Mammalia and man. The laminated structure is here absent. There is a partial decussation of the fibres of the two nerves, while another portion is continued to the retina of the same side. This structure is more evident in mammiferous animals than in man. The superior and external portion of each root of the optic nerve is, in the horse, continued to the eye of the same side; the rest of the fibres decussate, and form part of the nerve of the opposite side.†

The microscopic structure of the *retina* has been recently elucidated by the discoveries of Treviranus,‡ with which the observations of Gottsche§

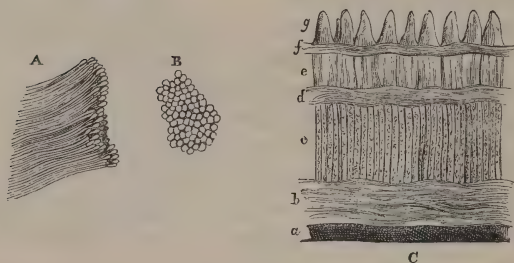
* J. Müller, *Physiol. des Gesichts-sinnes*, tab. 3, fig. 19. † Ibid. tab. 2. figs. 4, 5.

‡ Beiträge zur Aufklärung des Organischen Lebens. Bremen.

§ Pfaff's Mittheilungen aus dem Gebiete der Medicin, 1836. Heft 3, 4. [The most internal fibres of the cerebral portion of each optic nerve are, according to Mr.

also are in accordance. The following description takes account of all the most important points in the structure of this part:—The retina consists of three principal layers; an external pulpy or pavement-like layer of granules, a middle fibrous layer, and an internal layer composed of erect cylinders, which is the continuation of the fibrous layer. The optic nerve, at its entrance into the eye, divides into the cylindrical nervous fibres which radiate out in the middle fibrous lamina of the retina. Each nervous fibre, or each fasciculus of several fibres, bends, as Treviranus discovered, at a certain point of its course, from the horizontal direction towards the opposite internal surface of the membrane,

Fig. 83.*



where it ends as a papilla (fig. 83). The diameter of the nervous fibres was in the hedgehog 0.001 millim. [$\frac{1}{2116}$ of a line]; the diameter of the papillæ in the rabbit 0.0033 millim. [$\frac{1}{641}$ of a line]; in birds from 0.002 to 0.004 millim. [$\frac{1}{1058}$ to $\frac{1}{529}$ of a line]. In frogs the fibres measured 0.0044 millim. [$\frac{1}{481}$ of a line], and the papillæ 0.0066 [$\frac{1}{320}$ of a line] in diameter. The retina in all classes of Vertebrata,

Mayo, continuous in the commissure with corresponding fibres of the opposite nerve; these would be, as Mr. Solly remarks, strictly commissural fibres. The innermost fibres of the nerves beyond the commissure are also described by Mr. Mayo to be united in a similar manner by a sort of loop, and not to be continued backwards through the chiasma.]

* [Fig. 83. Structure of the retina, after Treviranus.—A. Portion of retina of a sheep seen from the outer side, showing the cylindrical fibres, and at the right hand border some of the papillæ, in which the fibres terminate on the inner surface of the retina; B. papillæ seen on the inner surface of the same retina; C. a thin perpendicular section of the retina of the hooded crow (*Corvus cornix*), which had been hardened by maceration in spirit; *a*. internal lamina of choroid; *b*. layer of cellular tissue, in which the fibres of the retina radiate out; *c*. perpendicular portion of the fibres of the retina; *d*. second layer of cellular tissue, containing a network formed by branches of the arteria centralis retinæ, and giving a sheath of this vascular layer of retina to the nervous fibres; *e*. larger nervous fibres which have acquired this sheath; *f*. third cellular layer perforated by the papillæ (*g*).]

if examined in the fresh state, is seen to have on its internal surface a layer of cylinders arranged closely side by side, with one extremity directed towards the cavity of the eye. These cylinders, or rod-shaped bodies, separate very easily from the subjacent membrane, and are seen floating free in the field of the microscope. In fishes they have small enlargements or papillæ, of which Gottsche has given an exact description. These rod-shaped terminations of the nervous fibres upon the internal surface of the retina must be examined in the perfectly fresh state. They very quickly undergo change after death, particularly in the summer season; and in their place there is seen merely a layer of granules, which were frequently observed in the earlier investigations into the structure of the retina. Although the three layers of the retina certainly exist, and although the rod-shaped bodies composing its internal lamina are very distinct, having been seen by Volkmann, E. H. Weber, Gottsche, Ehrenberg, and myself, yet the essential nature and mode of connexion of these bodies with the fibres of the fibrous layer are still involved in obscurity. It is a question, namely, whether the rod-shaped bodies correspond exactly in number to the nervous fibres, and whether each fibre actually corresponds to one of those bodies; or whether the latter are superposed in series upon the fibres of the fibrous layer.

Conditions necessary for vision.—Owing to ignorance of the physical conditions necessary for vision, it has become a current opinion that there are animals endowed with the perception of light by their skin. It cannot be doubted that many animals which have no eyes are sensible of the influence of the principle of light; thus, Rapp* observed that the *Veretillum cynomorium*, one of the Polypifera, avoids the light, and prefers shaded situations.† But, with respect to the mode of action of light on such animals, we have no facts to prove that it produces in their skin, or the entire surface of their body, really the sensation of light, and not another kind of sensation. We ourselves are sensible of the action of light on our skin by the sensation of warmth which it produces, but do not thence derive any sensation of light; for, as far as we can judge from facts, the optic nerve alone is susceptible of that sensation. The action of light on the lower animals destitute of eyes

* Nova Acta Acad. Nat. Cur. xiv. p. 2.

† With respect to the *Hydræ* no decided result has been obtained, notwithstanding the experiments of Trembley, Baker, Hanow, Roesel, Schaeffer, Bonnet, and Goeze. Ingenhous and Goldfuss relate that the green matter of Priestley collects especially in places exposed to a bright light. This green matter, which collects in such situations, may certainly consist of living infusory animalcules, since many of these creatures have a green colour, and many indeed have, according to Ehrenberg's observation, eye-dots. What is usually called the green matter of Priestley, however, often consists merely of the dead remains of green Infusoria, as the *Euglena viridis* and others.

may be similar to its action on the surface of our body. Even plants are strongly affected by its influence; the direction in which they grow and spread their branches is regulated by their tendency to bend towards the light.

The connexion of the sensation of light solely with special nerves endowed with a specific sensibility is proved by the actual existence of eyes in many of the animals lowest in the scale of organisation. Many of the Annelida, as several of the Nereida, several species of Eunice, Phyllodoce, Spio, and Nais, almost all the Hirudo family, and the Aphrodite heptacera, have dark eye-dots on their head. An annelide nearly allied to Sabella, and observed by Ehrenberg, Henle, and myself, has two such dark points at each extremity of its body; and it creeps both forwards and backwards. The Hirudo medicinalis has, as E. H. Weber pointed out, ten dark eye-dots on its head, which in the embryo are distinctly visible, the body being yet transparent. The Planariæ have on their head eye-dots rendered visible by pigment. Similar eye-dots have been observed in several Cercariæ and Rotifera by Nitzsch, Dutrochet, Gruithuisen, and Ehrenberg. The last-mentioned naturalist has discovered the existence of such dots of pigment, or eyes, in many Infusoria, and also in the Asterias family, at the extremity of the divisions of their body, which they elevate in swimming; and he has rendered it probable that the bodies containing pigment, which exist at the margin of the disk in the Medusæ, have a similar function.* I have demonstrated the optic nerves in the dot-like eyes of the Annelida, and Ehrenberg has shown that the nerves in the arms of the Asterias are continued to the eye-dots at their extremity.

Gruithuisen† supposes that every dark spot of the skin has in some degree the nature of an organ of vision, since it absorbs more light than other parts. This is evidently an error; for the primary condition for vision is the specific sensibility of a nerve having other endowments than those of the nerves of mere common sensation or touch.

The very structure of the eyes in the Annelida proves, moreover, that, even for the mere distinguishing of day from night, a special nerve and an organ are necessary; for, as I have already shown at page 1110, the eyes of these animals are totally destitute of optical apparatus for the formation of images, and are consequently incapable of distinguishing any objects. Nature, therefore, where it aimed merely at the power of distinguishing light from darkness, has formed organs for that purpose; and it is probable that the eye-dots of the Planariæ, Asterias, Rotifera, and Infusoria have this function.

A second critical remark, which suggests itself in connexion with this

* Müller's Archiv. 1834.

† Isis, 1820, 251.

subject, relates to the opinion that, by virtue of the exaltation or transposition of sensibility, it is possible for persons to see with the skin.

It is a known fact that we cannot, by means of the fingers, recognize colours as such ; although it may be possible to distinguish the corpus or grain of some colouring matters when laid thickly upon a surface, since they are uneven, and adhere to the skin which touches them. The necessity for an optical apparatus for the production of an image upon a percipient membrane sufficiently refutes the notion of persons being able to see with their epigastrium, or with the fingers, when in the so-named magnetic or mesmeric states. Even though the skin of the epigastrium or fingers were susceptible of the sensation of light, which they are not, the perception of objects would yet be impossible, unless there were optical apparatus for collecting the light radiated from certain points of the object upon certain corresponding points of the sensitive surface ; and, without such apparatus, the epigastrium and fingers, though they possessed the sensibility for light, would merely be able to distinguish light from darkness. Since, however, these parts are not susceptible of the sensation of light, and since no sense can be transferred from one part to another, it is quite impossible for a person in the magnetic state to have even an obscure perception of light and darkness by means of any other parts than the eyes. Moreover, when the eyes are bound, it is still possible to distinguish the light, and even objects, by slightly raising the eye-lids, as every one well knows who has played at the game of "blind-man's buff;" and persons lying, like the subjects of the pretended magnetic sleep, in the horizontal posture with their eyes bound, can see every part of the room by looking under their bandage. But what well-informed physician can put faith in the fables told by the upholders of animal magnetism ? It is quite in accordance with the laws of science that a person sleeping shall have ocular spectra,—we experience them sometimes when the eyes are closed, even before falling asleep,—for the nerves of vision may be excited to sensation by internal as well as by external causes ; and so long as a "magnetic" patient manifests merely the ordinary phenomena of nervous action that are seen in other disorders of the nervous system, it is all credible enough. But when such a person pretends to see through a bandage placed before the eyes, or by means of the fingers or the epigastrium, or to see round a corner and into a neighbouring house, or to become prophetic, such arrant imposture no longer deserves forbearance, and an open and sound exposure of the deception is called for.

II. *Theory of vision deduced from the structure of the eye.*

Vision, or the formation of images, requires a very different theory, according as the eyes are constructed of transparent cones disposed

in a radiate manner, and having their lateral surfaces so covered with pigment, that the light which passes in the direction of their axis can alone reach the retina, which is the case with the compound eyes of insects and Crustacea, — or like the simple eyes of insects, Arachnida, Mollusca, and Vertebrata, have concentrating refractive media, a cornea with or without aqueous humour, a lens, and a vitreous body.

*A. Of the mode in which vision is effected by the compound eyes of Insecta and Crustacea.**

The process of vision in insects and crustacea with compound eyes is the more interesting, inasmuch as it is totally different from that which subsists where the eyes have a structure similar to the human eye, and affords an insight into the nature of vision generally. The structure of the compound eyes of insects has been described in the preceding pages.

As long as the transparent cones coated with pigment, which are intermediate between the cornea and retina, received no attention, or the fibres of the optic nerves were supposed to extend to the facets of the cornea, the vision of insects was quite inexplicable. If the fibres of the nerve extended as far as the cornea, each luminous point, *a*, *b*, *c*, or *d*, lying in front of the eye, would cast rays of light upon all the fibres of the nerve, *a*, *b*, *c*, and *d*, at the same time; in other words, the points *a*, *b*, *c*, and *d*, could not be distinguished from each other, but merely a certain general impression would be produced. The cones, however, prevent any light from reaching the nervous fibres corresponding to them, except that which enters them in the direction of their axis or of the radii of the eye; while all the rays of light which fall upon the sides of these cones are absorbed by the pigment covering them. In consequence of this, each cone represents an aliquot portion of the image, which is composed, like a mosaic-work, of as many parts as there are cones in the eye, and the distinctness of the image necessarily increases with the number of the cones.

Distinctness and indistinctness of the image.—The image formed in the eyes of insects and Crustacea, and that received upon the retina of eyes constructed with concentrating refractive lens-like apparatus, owe their distinctness respectively to very different causes. In the latter case, distinctness is due to the retina being situated at the proper focal distance from the lens. In the former, it depends merely on the size of the eye, and the number of cones or facets which contribute to compose the image. When the eye contains 12,000 such bodies for isolating the rays of light, 12,000 divisions of the field of vision will be separately

* J. Müller, *Physiol. des Gesichtsinnes*, p. 315.—*Ann. d. Sc. Nat.* t. xvii. p. 232.

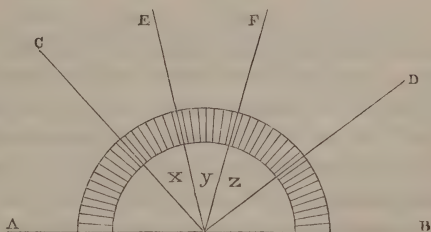
represented in the image. But, when the number of these bodies is small, each cone and each facet will admit the rays from a much larger portion of the visual field, and the image in each of these areas will produce a confused impression, and not a distinct representation of the different luminous points; for all the luminous points from which the rays fall upon the same cone, and the same nervous fibre corresponding to this cone, will excite but one mixed sensation. The length of the cones also must have an influence on the distinctness of vision by these eyes; for, the longer the cones, the more perfectly will all the oblique rays be prevented from reaching the optic nerve, so that the impression of light will be more exclusively produced by the rays coming in the direction of the axis of the cone.

Vision of near and distant objects.—From the foregoing explanation of the process of vision in compound eyes, it follows that a great difference must exist between them and the eyes furnished with lenses in relation to the perception of near and distant objects. The action of the compound eyes remains the same whether the objects be near or distant: in neither case is any change of adaptation within the eye necessary; for a separate image will always be formed by those rays which traverse each cone in the direction of its axis, whether those rays come from a corresponding part of a near or of a distant body. The number of distinct points in the external world which are represented by one point only in the compound eye, will of course be greater as the distance of the object increases; but still there will be no halo produced, from the want of the rays being brought to a focus, and no change in the arrangement of parts in the interior of the eye will be necessary for the improvement of the image.

Size of the field of vision.—The extent of vision of an insect may be very exactly deduced from the form of the eyes; for, since no objects are seen but those which lie in the direction of the axes of the cones, or of the radii of the spherical surface of the eye, the axes of those cones which form the border of the eye, being extended on-wards, will mark the limits of the field of vision. In other words, the greater the segment of a sphere which the eye of an insect represents, the more extensive will be its field of vision, and *vice versa*.

An eye of hemispherical form (fig. 84) will receive the image of all bodies which lie in front of it, from the radius A to the

Fig. 84.



radius B; an eye corresponding in convexity to the segment of a circle, C D, would receive the impression of the rays of light emitted by objects lying between the lengthened radii C and D; and the field of vision for an eye corresponding to the smaller segment of a sphere, E F, would only be such as would be included by the radii E and F. Since a body is less convex in proportion as the segment of a sphere which it represents is smaller, we may express this law by saying, that the less convex the eye is, the smaller will be its field of vision. The eye of a *Libellula* (or dragon-fly) has, for example, a field of extraordinary extent, for it forms more than half a sphere; it must receive the image of objects before and behind it, as well as at the side. The motions of this insect correspond with the developement of its eye, for they are very quick and sure; and their direction is changed at will, and often suddenly, towards either side. The slightly convex eyes of some *Hydrocorizæ* (water-bugs), which are scarcely raised above the surface of the head, and form a very small segment only of a sphere, must have a confined field of vision. In *Naucoris* and *Notonecta* these flat eyes lie at the front of the head, and we cannot therefore be surprised at the motions of these insects in the water being in accordance with the limited size of their field of vision. They move merely straight forwards, and do not vary their course from side to side.

It is evident that the absolute size of the eye cannot have the slightest influence on the extent of the field of vision. An eye may be very small, and yet have a large field, if it correspond in convexity to a large portion of a sphere; while, on the other hand, a large eye may have a very limited field of vision, if its surface be only slightly convex, so as to represent a small segment of a sphere.

Angle of vision.—It will be at once seen, from the remarks already made, on what depends the relative size of the images in comparison with the whole field of vision of an insect. The limits of the image of each object are determined by the rays of light which, issuing from the points of the object, fall upon the eye in the direction of the axes of the transparent cones. If we imagine these rays to be continued behind where they fall upon the eye until they meet, the angle included between them would be the angle of vision—*angulus opticus*. Or if we imagine the circle, of which the convexity of the eye in a section of it forms a part, to be completed, and the circle thus produced to be divided into degrees, minutes, and seconds, the distance of the points upon the surface of the eyes will be expressed in the measurements of angles. Now, since the relative size of the image, in comparison with the object, always depends on the position of the cones through which the rays of light from the individual points of the

object pass, the size of the angle of vision for any object may be determined in degrees, minutes, and seconds, the distance from each other of the cones which admit the rays from the extreme points of the object being known. Objects at different distances from the eye, but transmitting their luminous rays to the optic nerve through the same cones, will, of course, form images of equal size, their angles of vision being the same. Thus, a body extending from the line C to the line E in the fig. 84, would always be seen under the same angle X; and its apparent size, in proportion to the field of vision, would be as X to 180° . The smallest angle of vision under which an insect will be able to distinguish one object from another, will be that which is included between the axes of two contiguous cones. Since many thousand cones are contained in one eye, we may form a general idea of the acuteness of vision of these animals.

From the consideration of the mode of action of these compound eyes in vision, it will be evident that no modification of structure is necessary to adapt them for the performance of their function in the air, or in water; for the conditions for vision remain the same in both cases, and, according to my observations, there are no structural differences between the eyes of aquatic insects and those of insects living in the air. In eyes in which the image is formed by the concentrating refractive action of lenses, a greater refractive power of the lens is necessary when the animal lives in the water than when vision is performed only in the air, on account of the difference between the density of the lens and water being less than that between the lens and air; but in the compound eyes of insects the refracting power of the transparent media has scarcely any share in the process of vision, and each cone transmits alike the rays from the object opposite to it, whether the surrounding medium be air or water.

The most perfect compound eye will be that which is fitted for seeing distinctly by its absolute magnitude, by the great number of its facets and cones, and by the length of these cones; and which has an extensive field of vision, owing to the convexity of its surface being such that it forms a great part of a sphere.

B. *Of the process of vision in eyes with concentrating dioptric media.**

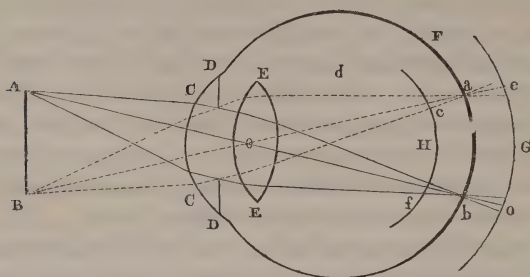
In the compound eye of insects and Crustacea vision is effected by the radiating cones transmitting to the optic nerve those rays only of the cone of light emitted by each point of the object, which have the direction of the axes of the cones, or of the radii of the eye, while the rest of the rays are absorbed. In eyes furnished with collective or concentra-

* After the treatises of Treviranus, Tourtual, Hueck, and Volkmann.

tive refracting media, the cone of light emitted by each point of the object is collected again to a point upon the sentient retina.

The refraction of the rays of light in the eyes of man and the higher Mammalia is, however, threefold. The rays of the cones of light

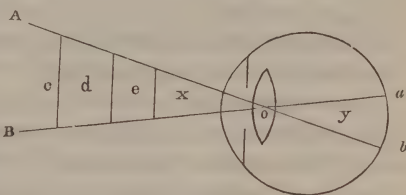
Fig. 85.



emitted by the points A B, and every other point of the object, (see fig. 85,) are first refracted by the cornea C C, and the aqueous humour contained between it and the lens,—that is to say, the rays are bent towards the axis of the cone of light; the media just mentioned having the power of refracting light by virtue of their density being greater than that of the air, and by reason also of their convexity. The rays of each cone of light are again refracted and bent still more towards its central ray or axis by the anterior surface of the lens E E; this body having a greater density than the aqueous humour, and its anterior surface being convex. The rays are again refracted in passing out of the lens into the less dense medium of the vitreous humour. It was shown in the preceding chapter, at page 1094, that a lens has the power of refracting the rays of a cone of light so as to bend them towards the axis of the cone, not only on their entrance from a rarer medium into the anterior convex surface of the lens, but also at their exit from its posterior convex surface, when they pass again into the rarer medium. In this manner the rays of the cones of light issuing from the points A and B are again collected to points at *a* and *b*; and, if the retina F be situated at *a* and *b*, perfect images of the points A and B will be perceived: but if the retina be not at *a* and *b*, but either before or behind that situation,—for instance, at H or G, circular luminous spots *c* and *f*, or *e* and *o*, instead of points, will be seen; for at H the rays have not yet met, and at G they have already intersected each other, and are again diverging. The retina must therefore be situated at the proper focal distance from the lens, otherwise a defined image will not be formed, or, in other words, the rays emitted by a given point of the object will not be collected into a point upon it. In the preceding chapter it was

shown that the focal distance of the image is greater, the nearer the object to the lens, and *vice versâ*. The direction given to the rays by their refraction is regulated by that of the central ray, or axis of the cone, towards which the other rays are bent. The image of any point of an object is therefore always formed in a line identical with the axis of the cone of light, as in the line Ba , or $A b$. The central ray of a cone of light will, it is true, itself suffer deviations from its straight path, if it do not pass through the axis of the lens, but impinge in an oblique direction upon it as well as upon the cornea. But these deviations may be disregarded for the present; and the spot where the image of any point will be formed upon the retina may be determined by prolonging the central ray of the cone of light, or that ray which traverses the centre of the pupil. Hence, for the preceding figure, the

Fig. 86.



following (fig. 86) may be substituted. $A b$ is the axis or central ray of the cone of light issuing from A ; $B a$, the central ray of the cone of light issuing from B ; the image of A is formed at b , the image of B at a , in the inverse position; therefore what in the object was above, is in the image below, and *vice versâ*,—the

right-hand part of the object is in the image to the left, the left-hand to the right. These facts can be verified by an experiment on the eye of a quadruped. If an opening be carefully made in an eye at its superior surface, so that the retina can be seen through the vitreous humour, the image of any bright object, such as the windows of the room, will be perceived at the bottom of the eye. The experiment may be performed still more easily, as Magendie pointed out, by means of the eye of any albino animal, such as a white rabbit, in which the coats, from the absence of pigment, are transparent: such an eye being dissected clean, and held with the cornea towards a window, a very distinct image of the window completely inverted is seen depicted on the posterior translucent wall of the eye.

The angle x , included between the decussating central rays of two cones of light issuing from different points of an object, is called the optical angle—*angulus opticus s. visorius*. This angle becomes larger, the greater the distance between the points A and B (fig. 86); and since the angles x and y are equal, the distance between the points a and b in the image on the retina increases as the angle x becomes larger. Objects at different distances from the eye, but having the same optical angle, x ,—for example, the objects c , D , and e ,—must also throw images of equal size upon the retina; and, if they occupy

the same angle of the field of vision, their image must occupy the same spot in the retina.

We have hitherto regarded those rays of the cones of light which traverse the middle of the pupil, and therefore pass through the crystalline lens near its centre, as determining the situation of the image on the retina. In this supposition, however, there is a slight inaccuracy,—that is to say, a line drawn from a given point of the object through the middle of the pupil would not fall exactly upon the corresponding point of the image on the retina; for even the central rays of a cone of light, when they fall obliquely upon the cornea and lens, suffer refraction from their original direction. Hence it follows that the actual direction of the central ray of a cone of light can be found only by experiment and calculation, and that the law laid down with regard to the optical angle requires some modification. The points of the image $a b$ will not lie in the prolongation of the lines $B o$ and $A o$.

It now remains to determine how far a straight line drawn from the object to the image would differ in direction from the central ray passing through the centre of the pupil.

I cannot enter into a full discussion of this problem, and will merely give the result of experiments instituted with a view to its elucidation. The valuable observations of Volkmann show that there is a point in the eye where the lines drawn from different objects to their images on the retina intersect each other; and that this point lies neither in the middle of the pupil, nor in the middle of the lens, but behind the lens.

Since the surface upon which the images are formed in the eye is concave, and from its centre towards its margins gradually approaches the lens, it necessarily follows that the images of objects situated at the sides cannot be so distinct as those of objects nearer to the middle of the field of vision, of which the images are formed at a distance behind the lens exactly corresponding to the situation of the retina. The indistinctness of the side images has, however, other causes besides this. The rays of a cone of light from an object situated at the side of the field of vision do not meet all in the same point, owing to their unequal refraction; but the main cause of the images of objects depicted on the retina becoming less distinct as they are more distant from its centre, seems to lie in a peculiarity of that membrane itself.

The refraction of the rays which pass through the circumference of the lens, and of those traversing its central portion, being unequal in consequence of “spherical aberration” (see page 1099,) a contrivance for the prevention of indistinctness of vision from this cause was required in the eye, like that employed in optical instruments,—namely, a diaphragm to cover the circumference of the lens, and to prevent the rays from passing through any part of the lens but its centre; this

diaphragm is the iris, and the central opening for the transmission of the rays, the pupil. The iris has, however, this advantage over the diaphragms of optical instruments, that it is mobile,—has the power of dilating and contracting. The dilatation of the pupil in the dark, or in a feeble light, has the good effect of admitting more luminous rays, even though the image is rendered less distinct. But even the image formed by the rays passing through the circumference of the lens when the pupil is much dilated may, under certain circumstances, be well defined; the image formed by the central rays being then indistinct or invisible, in consequence of the retina not receiving these rays where they are concentrated to a focus. The image must be most defined and distinct when the pupil is narrow, the object at the proper distance for vision, and the light abundant; so that, while a sufficient number of rays are admitted, the narrowness of the pupil prevents the production of indistinctness of the image by spherical aberration or unequal refraction.

With respect to the lens, we may remark that it must be more dense and more convex, in proportion as the difference between the density of the medium in which the animal lives, and that of the aqueous humour, is less. In fishes the lens is spherical, and the cornea generally flattened. In animals which live in the air, the cornea is more convex, and the lens much less so.

The interior of the eye, namely, the posterior surface of the iris and ciliary processes, and the inner surface of the choroid, immediately external to the retina itself, is coated with black pigment, which has the same effect as the black colour given to the inner surface of the walls of optical instruments. It absorbs any rays of light which may be reflected within the eye, and prevents their being thrown again upon the retina so as to interfere with the distinctness of the images there formed. This is the use of the pigment on the posterior surface of the iris and ciliary processes. But the coating of the outer surface of the retina by the pigment of the choroid is also important in the same respect; for the retina is very transparent, and if the surface behind it were not of a dark colour, but capable of reflecting the light, the luminous rays which had already acted on the retina would be reflected back again through it, and would fall upon other parts of the same membrane, the consequence of which would be not merely dazzling from the excessive action of light, but also indistinctness of the images. Animals in which the choroid is destitute of pigment, and human albinos suffer in this way; they are dazzled by daylight, and see best in the twilight.

In many animals, which are most active and hunt their prey when it is becoming dark, but are sluggish during the day, as in the cat family and other nocturnal animals, the portions of their choroid destitute of

pigment, or rather covered with white pigment in place of black, are of service by increasing the action of the luminous rays upon the retina.

The distinctness of the image formed upon the middle portion of the retina is dependent on several very different conditions: namely, 1, on the rays emitted by each luminous point of the object being brought to a perfect focus upon the retina without any halo being produced; 2, on the sufficiency of the illumination; 3, on the small size of the elementary parts of the retina which are susceptible of distinct sensation.

The first condition, namely the necessity of the focus of the cones of light falling exactly upon the retina, is the cause of the different distances at which different persons see distinctly; some persons being short-sighted, others long-sighted; while in others, again, there are no such narrow limits to the sphere of distinct vision, their eye being able to adapt itself for the formation of the image upon the retina according to the distance of the object. Since, however, this power of adaptation of the eye for vision at different distances has its limits, there is in every individual a distance at which he sees most distinctly, and at which the focus of the image formed by the refracting media of his eye corresponds most accurately with the situation of his retina. This "*distantia visionis distinctæ*" may be stated at from five to ten feet [query, inches] in the majority of individuals. Objects which are too near the eye throw very indistinct images upon the retina; a slender body, such as a pin, held close to the eye, cannot be seen at all, or produces only an undefined impression on the retina. Few persons, on the other hand, are able to read print at a much greater distance than twenty inches. The refractive power of the transparent media of the eye is the source of great differences in this respect. Short-sighted or myopic persons see the nearest object distinctly, while they cannot discern distant objects; long-sighted persons can see a small body which is not very visible, only when it is held at a considerable distance from their eyes.

The second condition for distinctness of vision is an adequate quantity of light; excess as well as deficiency of light causes the images of objects to be indistinct.

The third condition is the minute size of the ultimate divisions of the retina capable of independent sensation. An illustration of this is afforded by bodies of which the surfaces are marked with very fine alternate black and white lines. Engravings viewed at such a distance that the images of the black and white lines fall together upon portions of the retina of a certain degree of minuteness, cannot be distinguished as separate lines, and produce merely the mixed impression of grey; the same remark applies to very fine lines of different colours regularly alternating with each other,—for instance, blue and yellow lines: in this case the impression of green will be produced. Hence it is that all

mixtures of two different colouring matters are seen, not as two colours mixed, but as a single intermediate colour. There must therefore be ultimate portions of the retina in which all simultaneous impressions are perceived as one only, and are not distinguished as occupying distinct places in the field of vision, even when they really are distinct in the image formed by the refracting media. The idea immediately suggests itself, that these ultimate sentient portions of the retina may be the papillæ or rod-shaped bodies of its internal lamina; and it would appear probable that different luminous rays impinging simultaneously on the different points of the surface of such minute portion or papilla of the retina will not be perceived as distinct rays, but that each papilla will receive from all one mixed impression only, and will propagate such an impression to the optic nerve. On this supposition the image perceived in these eyes must be composite, like a piece of mosaic-work, in which each elementary portion is in itself homogeneous. In accordance with this view, it is found that the ultimate anatomical elements of the retina agree pretty nearly in size with the smallest portions of the retina ascertained by experiment to be capable of separate sensation. The smallest angle under which two points can be distinguished by many persons is $40''$. From this, Smith calculated that the size of the smallest portion of the retina endowed with distinct sensation is $\frac{1}{8000}$ of an inch; and according to the measurements of Treviranus, the diameter of the papillæ of the retina in the rabbit is 0.0033 millim.; in birds from 0.002 to 0.004 millim. Now, 0.003 millim. equals $\frac{1}{33000}$ of an English inch, and 0.004 millim. = $\frac{1}{25000}$ of an English inch. The mean between 0.003, and 0.004 millim. or, as an approximation, between $\frac{1}{8000}$ and $\frac{1}{10000}$ of an inch, being therefore assumed as the diameter of the papillæ of the retina, the size of these parts would agree very exactly with that of the smallest portions of the surface of that membrane capable of distinct sensation. The measurements of the globules of the human retina, taken by E. H. Weber some years since, also accord with this view: he found their diameter to be between $\frac{1}{8000}$ and $\frac{1}{8400}$ of a French inch.

According to other data, however, no such agreement is found to prevail; and Volkmann's observations render it probable that the discriminating power of the retina is much greater than it could be, were the nervous fibres its ultimate elements. Muncke assumes $30''$ as the smallest angle at which an object can be distinguished; Treviranus could discern a black point 0.00833 of an inch in diameter, upon a white ground, at a distance of 48 inches; and Volkmann calculates that the diameter of the smallest image perceived by the retina is $\frac{1}{100000}$. Even this estimate of the discerning power of the retina he regards as too low: any eye of moderate power can, he says, see a hair $\frac{1}{1000}$ of an inch in diameter at the distance of 30 inches, when an image on the

retina of 0.000023 of an inch only would result. A pupil of Von Baer could see a hair $\frac{1}{60}$ th of a line in diameter at the distance of 28 inches, in which case Volkmann calculates that an image $\frac{1}{0.0000014}$ of an inch was perceived in the retina. Volkmann concludes, therefore, that, even disregarding the last extraordinary instance, the smallest images perceived in the retina are smaller than the most minute known anatomical elements of that structure.

III. *Adaptation of the eye to vision at different distances.*

It will have been perceived, from the facts already stated, that some changes in the internal condition of the eye are necessary for the purpose of distinct vision at different distances. The focus of the image of distant objects is somewhat nearer to the lens than that of the image of near objects. The amount of the difference in the focal distances for near and distant objects, as deduced from the refractive powers of the media of the eye, has been calculated by Olbers.* We shall extract some of the results of his calculations, in order to give an accurate idea of the degree of modification required in the eye. The distance of the image from the cornea when the objects were at the distances of 4, 8, and 27 inches, and at infinite distance, so that the rays were essentially parallel, was found to be respectively as follows :

<i>Distance of the object.</i>	<i>Distance of the image from the cornea.</i>
Infinite	0.8997 of an inch.
27 inches	0.9189 „
8 „	0.9671 „
4 „	1.0426 „

So that the difference between the focal distances of the images of an object at such distance that the rays are parallel, and of one at the distance of 4 inches, was only 0.143 of an inch. On this calculation the change in the distance of the retina from the lens required for vision at all distances, supposing the cornea and lens to maintain the same form, would not be more than about one line, which might be effected either by elongation of the eye, or by a change in the position of the lens. Dr. Young estimated the necessary change at $\frac{1}{6}$ th of the length of the axis of the eye.

It will be conceived that the same object might be attained, without any alteration in the distance of the lens from the retina, by a change in the convexity either of the cornea or lens.

Olbers has also calculated the amount of change in the convexity of the cornea which would be required for distinct vision at different distances. The radius of the convexity of the cornea for vision

* See his excellent treatise, *De Internis Oculi Mutationibus*. Gött. 1780.

at certain distances, taken for the sake of examples, would be as follows :

<i>Distance of the object.</i>	<i>Radius of the corneae.</i>
Infinite	0·333 of an inch.
27 inches	0·321 "
20 "	0·303 "
5 "	0·273 "

If the radius of the cornea were capable of modification between 0·333 and 0·300 of an inch, and the long axis of the eye capable of being lengthened the extent of half a line, distinct vision at all distances beyond four lines would be provided for. These results may serve as the basis of the following inquiry.

The absolute necessity of such internal changes in the eye to adapt it for distinct vision at different distances appears a matter of certainty. Nevertheless, some physiologists—as, De La Hire, and Haller, and more recently Magendie, Simonoff,* and Treviranus,†—have called in question the capability of the eye to undergo such internal changes: most cultivators of physics and physiology, however, regard the reality of these changes of adaptation as proved by certain facts. Magendie founds his scepticism on the observation that the image in the eye of a white rabbit does not diminish in distinctness when the distance of the object is altered; which is not, however, a constant fact. G. R. Treviranus, from a calculation of the action of lenses which increase in density towards their interior, arrived at the conclusion that with lenses of this structure the focal distance would remain the same whatever the distance of the object, and consequently that no adaptation of the eye for different distances is required.

Much as we may admire the elegant manner in which Treviranus has treated this subject with the aid of mathematics and the laws of optics, yet we must confess that the results of his calculation do not accord with the facts observed in the eye itself. Moreover, Kohlrausch‡ controverts the accuracy of Treviranus's deductions. That the eye does undergo changes to adapt it for distinct vision at different distances is indeed proved incontestably by simple and accurate experiments. They are as follows :

1. The power which the eye possesses of accommodating itself to different distances is frequently much modified in a short space of time. Not only does the constant use of the eye in regarding near objects induce short-sightedness in children, but frequently the same condition

* Journ. de Physiol. iv. p. 260.

† Beiträge zur Anat. u. Physiol. der Sinneswerkzeuge, 1823; and his Beiträge zur Aufklärung der Erschein. u. Gesetze des Organisch. Lebens. 1—3 Heft.

‡ Über Treviranus' Hypothese. 1837.

is produced as a transient state of a few hours' duration by long-continued use of the microscope. Under such circumstances, the perception of objects at 20 feet distance in the street sometimes becomes indistinct, though, before, the eyes could accommodate themselves well both to near and distant objects. This has frequently happened to me. The state of myopia thus induced lasts sometimes several hours.

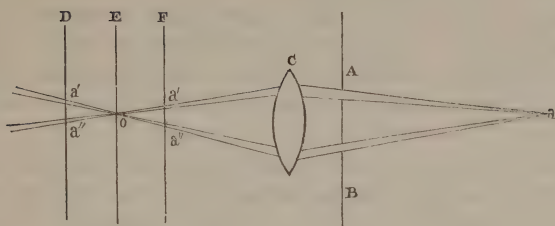
2. If we regard with one eye only (the other being closed) the ends of two needles placed one before the other at different distances in the line of the axis of the eye, one will be seen distinctly when the other appears indistinct, and *vice versâ*. Both the images lie in the axis of the eye, one over the other; and yet it depends on a voluntary effort, the exertion of which can be felt in the eye, whether the first or the second needle shall be seen distinctly. So that when with the pupil contracted, as it is for the vision of near objects, I fix my eye upon the nearest needle, the focal point of its distinct image being at the central point of the retina, the more distant one, though the central rays only of its cone of light can enter the eye, forms, nevertheless, an indistinct circle of light around the same central point of the retina; that is to say, the central rays of the more distant object do not meet in a focus at the central point of the retina, but anterior to it.* A variation of this experiment consists in looking at the head of a pin through a very small opening in a card. Here it is wholly dependent on the will whether the borders of the opening shall be seen distinctly, in which case the head of the pin becomes indistinct; or whether this should be seen distinctly, when the borders of the opening in the card cease to appear defined. Treviranus has not paid sufficient attention to these phenomena; and his explanation of them, by supposing the attention or nervous action being transferred from one part to another, is very unsatisfactory. The two images of the needles fall upon the same point of the retina, one lies over the other, and yet I see the nearer through the cloud-like image formed by the rays from the other more distinct needle, and *vice versâ*. There is here no transferring of the attention from one point of the retina to another. An entire leaf covered with letters appears indistinct to me, as soon as I produce the internal change in my eye necessary for distinct vision at a different distance, though no object be there.

3. Scheiner's experiment.†—If two pin-holes, A B, (fig. 87,) be made in a card, at a less distance from each other than the diameter of the pupil, and if these openings be held before one eye, so that a small object, *a*, can be seen through them, this object will appear single at one

* Jahrb. f. Wissenschaft. Kritik. 1829. Oct. 623.

† Scheiner, Oculus, sive Fundamentum Opticum.

Fig. 87.



particular distance from the eye, but when it is at any other distance it will appear double. Thus, if the object, a , be at such a distance that its single image, o , falls upon the retina E, it appears single; but, if its distance be greater, the focus of the image will be formed in front of the retina, and the rays, after intersecting each other, diverge and fall separately as a double image, a' , a'' , upon the retina, as at D; and, of the two images, the lower, a'' , will disappear when the opposite or upper opening, A, in the card is closed, and *vice versa*. In the same way, if the object, a , be too near the eye, the single image is formed behind the retina, which in this case also receives a double image a' , a'' , as at F; and, of these, the lower a'' will disappear, when the corresponding opening B, in the card is closed.

The conclusions to be deduced from this experiment have been pointed out by Porterfield, Young,* Purkinje, Plateau, and Volkmann, and the last-mentioned physiologist has varied the mode of performing it in several ways. The experiment of Scheiner proves clearly the necessity of adaptation of the eye for distinct vision at different distances, and at the same time the incorrectness of the hypothesis of Treviranus, since it shows that the image of an object under certain circumstances falls in front of the retina, and under others behind it. An experiment of Beudant and Crahay has the same import. If a pin at the distance of five or six centimeters [2 or $2\frac{1}{2}$ inches] from the eye be viewed through a pin-hole in a card, and the card be moved from side to side, the needle will appear to move also, but in the opposite direction to the card. This is explicable in accordance with the phenomena of indistinct vision, resulting from the image of the object falling either in front of or behind the retina. Thus, if the rays meet at a focus in front of the retina, they will diverge again after having crossed at the focal point, and will form an indistinct spectrum upon the retina, not a definite image; and if in this case the card in its motion intercept a part of the decussating rays, those from one side only will reach the retina. Hence the apparent shifting of the image. The diffraction of the rays

* Philos. Transact. 1801.

at the margin of the opening in the card, however, has also a share in the production of this phenomenon.

The adaptation of the eye to distinct vision at different distances may be attributed to changes in several different parts, namely, to movements of the iris, to change of place of the lens, to elongation of the axis of the eye, or to alteration in the convexity of the lens or cornea.*

1. The movements of the iris have been considered the means of adaptation by some physiologists, amongst whom are Mile and Pouillet; Professor Mile supposed it to be effected by the inflexion or diffraction of the light at the margin of the pupil, by which the focal distance for the respective rays would be rendered very different. M. Pouillet thought the image would be formed by the central or by the peripheral rays, according as the pupil was contracted or dilated.

2. Elongation and shortening of the axis of the lens were regarded by Dr. Young as the means of accommodation. J. Hunter and Dr. Young ascribed to the lens a contractile power inherent in itself.†

3. Change in the convexity of the cornea was the explanation adopted by Sir E. Home, Englefield, and Ramsden: this change was supposed by Sir E. Home to be effected by the action of the proper muscles of the eye; or, in birds, by the peculiar muscle, discovered by Sir P. Crampton,‡ at the inner surface of the margin of the cornea.

4. The movement of the lens by means of the ciliary processes, or the zonula ciliaris, was assumed as the cause by Kepler, Scheiner, Porterfield, Camper, and many others.

5. Lastly, the influence of the muscles upon the form of the eye has been regarded as the cause of the internal change of adjustment by many writers, as Rohault, Bayle, Olbers, Home, and Schroeder van der Kolk, some of whom ascribe the influence in question to the m. recti, others to the m. obliqui.

That a connexion exists between the movements of the iris and the action of the eye, by which it accommodates itself to vision at different distances, cannot be denied; for, when distant objects are viewed, the pupil becomes dilated, when near objects contracted: and, notwithstanding the continued presence of a strong light, as of a lamp held before the eye, the size of the pupil may be very much modified at will by looking at objects at different distances; in doing which we cause the axes of the eye to converge while we regard the near object, and, on the contrary, give them a more parallel direction while a very

* A full account of all the hypothesis relative to this subject is given by Haller, *Element. Physiol.* t. v. L. xvi. Sect. 4. § 20; by Olbers, *loc. cit.*; and by Treviranus in his *Biologie*. Bd. vi. p. 512.

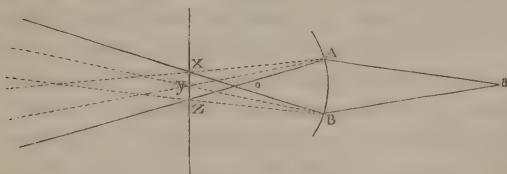
† *Philos. Transact.* 1794.

‡ [Thomson's *Annals of Philosophy*, vol. i. 1813, p. 170.]

distant object is the subject of our vision. These changes in the state of the iris are, however, merely associate movements, consequent on the *nervus motorius oculi* exerting an influence upon the ciliary or lenticular ganglion and the ciliary nerves, while it excites the action of the muscles of the eye-ball. Contraction of the iris always ensues as a result of associate or consentient nervous action, when even one eye only (the other being closed) is turned inwards, or inwards and upwards, and is in this way associated with the voluntary action of several muscles supplied by the third or motor oculi nerve. In these phenomena, therefore, we can recognise no immediate connexion between the motions of the iris, and the power of the eye to accommodate itself to different distances. But it remains to inquire how far distinct vision at different distances can be explained by these movements of the iris.

a. Mile* finds an explanation of the accommodating faculty of the eye in the motions of the iris, and the inflexion of the rays of light by its margin. The following is his view of the process. Let *a* (fig. 88)

Fig. 88.



be a given point in any object, the central rays of the cone of light emitted by which do not meet at a focus upon the retina, but in front of it; here, then, the point *a* cannot be seen through the medium of these central rays; but the peripheral rays of the cone, *a* A, and *a* B, which pass close to the margin of the iris, will suffer inflexion, and, instead of continuing their course in the direction A *o* and B *o* will take the direction A *y* and B *y*, and meet upon the retina at *y*. The border of the iris, therefore, by producing this inflexion, lengthens the point in which the rays meet, or their focus, beyond the focal distance of the central rays; and since the inflexion of the rays becomes greater the nearer they are to the margin of the iris, the point at which they meet will be more and more distant behind the lens the nearer they are to the margin of the pupil. The focus of the central and peripheral rays will not therefore be confined to any definite point behind the lens, but will extend through a line of some length; and the eye will in consequence of this be able to see distinctly, through the medium of the rays inflected by the margins of the iris, an object which the other rays would no longer

* Magendie's *Journal de Physiol.* vi. p. 166.

depict distinctly on the retina. The defect of this theory is, as pointed out by Treviranus and Volkmann, that it supposes a small proportion only of the rays to be employed in the formation of the image,—those, namely, which pass close to the margin of the iris,—while the greater mass of the light is not taken into account; and moreover that the foci resulting from the meeting of the rays at other points, as at x and z , are not noticed.

b. Pouillet's theory is based, not upon the inflexion of the rays by the margin of the iris, but upon the different focal distance of the central and peripheral rays; the first of which, being refracted by the central denser portion of the crystalline lens, are, he supposed, brought to a focus sooner than the latter, which pass through its marginal portion. The pupil becoming dilated during the vision of distant objects, and contracted when the eye is fixed upon near objects, the marginal rays will in the latter case be intercepted, and the central rays only will be brought to a focus. On the other hand, the image of distant objects will be formed by the peripheral rays; for the rays from distant objects being concentrated to a focus nearer the lens than corresponding rays from near objects, the focal distance of the peripheral rays will here correspond to the situation of the retina, while the central rays will meet and intersect each other in front of the retina, and form indistinct luminous circles upon it, which, however, do not excite the attention of the sensorium, on account of the intensity of the image formed by the marginal rays concentrated to a focus. The experiment before mentioned, of fixing one eye (the other being closed) alternately on the ends of two needles, placed one in front of the other at different distances from the eye, affords a complete refutation of this theory. While the needle nearest to the eye is seen distinctly the more distant one appears indistinct, and *vice versâ*; so that during the contracted state of the pupil for the vision of the near object, by which the peripheral rays of the cone of light are excluded, an imperfect image of the more distant object is still formed by the central rays proceeding from it, which have been concentrated to a focus in front of the retina. Whence this objection to the theory of Pouillet arises, that while the eye is fixed upon the more distant object and the pupil dilated, the central rays, notwithstanding the distinctness of the image formed by the peripheral rays, cannot be wholly without effect; and, if this be the case, the cause of distinct vision at different distances cannot be what Pouillet states.

c. This objection is of equal force against the view proposed by Treviranus, who admitted the change in the size of the pupil to be a cause, contributing with the varying density of the lens to effect the accommodation of the eye. According to his calculations, the crystalline lens will concentrate the rays from objects at any distance from the eye to a focus, if the size of the pupil be such as to modify,

in accordance with a law which he states, the proportion between the central and peripheral rays.

To all hypotheses which regard the accommodation of the eye to distances as a direct effect of the motions of the iris, we may, lastly, object with Volkmann, that any change in the size of the pupil produced by variation of the light ought, in that case, to disturb the state of adaptation of the eye; which is not in accordance with facts. The distinct perception of an object through an artificial pupil in a card, and the power of seeing through such a pupil either of two needles placed one before the other in the line of the axis of vision, also prove clearly enough, that the power of adjustment is not directly due to the change of size of the pupil, and that the alteration in size which the pupil undergoes, according to the distance of the object, is an indirect effect of some other cause. Looking through a point-like aperture in a card held close to the cornea, I can see the letters of a book distant fifteen inches, either distinctly or indistinctly, by a voluntary effort of my eye, and quite independently of the size of the artificial pupil in the card, which remains constantly the same.

The hypothesis that the adjustment of the eye is effected by a change of the convexity of the cornea, appears to be sufficiently refuted by the calculations of Olbers; for the compression of the eye by the action of its muscles is not capable of producing changes in the length of the radius of the surface of the cornea to the extent of 0.273 or 0.333 of an inch. Home and Ramsden maintained, it is true, that they had observed such changes in the living eye during the vision of near and distant objects; but Dr. Young was unable to verify this observation, and it would be impossible to determine the reality of such a change accurately by experiment, on account of the mobility of the eye. The best means of ascertaining this fact would be to observe whether small images reflected by the cornea, such as the image of a light window, change their size and position while the eye is adapting itself to the perception of point-like objects situated at different distances in the same line.

The view which attributes the adjustment of the eye to the alteration of its form by the action of the external muscles, is also not free from objections. The phenomena of vision at different distances are certainly explicable on such a view; but that does not prove its correctness, for there are many different ways in which these phenomena might possibly be produced. The action of the straight muscles can, as Treviranus remarks, scarcely be conceived capable of producing elongation of the axis of the eye in the manner Olbers supposes. He imagines, namely, that by the action of these muscles the vitreous humour is compressed, and made to extend itself anteriorly and posteriorly. But the tendency of the straight muscles is merely to retract the eye,

and, if resistance were afforded by the cushion of fat behind it, to flatten rather than elongate it; their action would therefore have the effect of adapting the eye to the vision of distant objects only, the image of which is formed nearer the lens than that of near objects: while it is in looking at very near objects, on the contrary, that we are conscious of an effort within the orbit. The compression and elongation of the eye might much more easily be effected by the oblique muscles; and Le Cameus, Rohault, and Schroeder van der Kolk have thus explained the accommodation of the eye. This view is in accordance with the circumstance that in the vision of near objects the axes of the eyes necessarily converge, to which movement the oblique muscles would contribute, as Luchtman has very ingeniously shown.* But this, as well as every other theory which attributes the adaptation of vision to distance to the action of the muscles of the eye, is open to objections. The state of adaptation of the eye can be entirely changed in a very short space of time by the local action of narcotics, the pupil becoming at the same time much dilated. This phenomenon cannot be explained by supposing the narcotic to be conveyed to the muscles of the eye and their nerves, since by imbibition the substance could reach only to a limited depth. Moreover, the motion of the eyes by means of the oblique muscles is not at all impeded by such local narcotization. The phenomenon in question is produced most readily by introducing a few drops of a weak solution of extract of belladonna into the eye. After a short time,—about a quarter of an hour,—the pupil becomes dilated, and at the same time the ordinary medium state of adaptation of the eye is found to be completely changed, though the power of adapting itself to different distances is not lost. Numerous observations relative to this phenomenon have been recorded. Most observers state that the eye is rendered long-sighted (presbyopic); while the experience of Purkinje, and a part of the observations of Volkmann, are opposed to this statement. The following is the result of my own observations:†—My vision is ordinarily perfect at all distances. It was remarkable that when the solution of the extract of belladonna was dropped into one eye, the other eye also was affected. When both eyes were open, that to which the narcotic was not applied had a refractive power adapted to the very nearest objects, which alone were seen distinctly, while the other eye did not perceive near objects distinctly. If it was desired to accommodate both eyes to distant objects, vision was more distinct, sometimes with the one eye, and sometimes with the other. If the eye immediately acted on by the belladonna was adapted for near objects, the other eye involuntarily

* Luchtman, *De mutatione axis oculi secundum diversam distantiam objecti*.—Trajecti ad Rh. 1832.

† *Physiol. des Gesichts-sinnes*, p. 200.

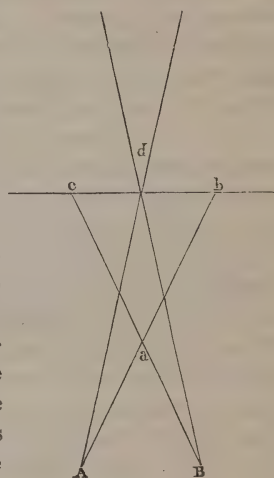
adjusted itself for the vision of the very nearest objects. The narcotized eye, therefore, though ordinarily presbyopic, had by no means lost the capability of adaptation. The iris also, although the pupil was very much dilated, had not quite lost its power of contracting. The eye could at will be made to discern, first near, and then distant objects distinctly; and, while the eye was fixed on distant objects, the iris was almost wholly retracted, but contracted somewhat, so as to narrow the pupil when the eye was voluntarily adapted to near objects. When objects were regarded with both eyes simultaneously, double images were generally seen, and the image appertaining to each eye was alternately more distinct, according as the simultaneous effort in both eyes brought the focus of the rays upon the retina of one or the other. When, by a voluntary effort, the narcotized presbyopic eye was accommodated to the vision of near objects, these appeared almost one-third smaller than natural, while the indistinct images depicted in the other eye (which under these circumstances saw only the very nearest objects distinctly) had their proper size.

If the hypotheses already considered be rejected, there will still remain those which place the means of accommodation to distances in the interior of the eye,—namely, in a change of position or form of the lens by the action of the ciliary processes, or zonula. Although these latter hypotheses cannot be directly refuted, they are equally incapable of proof; and such, in fact, is the state of the question generally; the phenomena may be explained in very different ways, but no one explanation can be proved to be more correct than another. Under these circumstances it will be more judicious to direct attention to some important facts, which are not taken cognizance of in any of the views above mentioned, and which, though they do not disclose to us the cause of the self-adjusting faculty of the eye, show its intimate connexion with other phenomena. The inquiries which I instituted in the year 1826 relative to double and single vision, led me to notice the connexion which subsists between the changes of adaptation to distances and the movements of the eye-balls themselves, by which their axes are altered in direction; a connexion as intimate as that between the changes of adaptation and the movements of the iris, or that between the movements of the iris and the movements of the axes of the eyes. Nearly all the writers who have treated of the accommodation of the eye to distances, have overlooked this important circumstance. Porterfield was, as Volkmann shows, the only one of the older physiologists acquainted with these phenomena.

With the same constancy that the iris contracts when the axes of the eyes are made to converge, and dilates when they are moved outwards to the parallel direction, does the eye adjust itself for the vision of near objects when the axes of the eyes converge, and for vision even

of the most distant objects when the eyes are turned outwards, so that their axes become parallel. It is well known that an object is seen distinctly when the eyes are fixed upon it, that is, when the axes of the eyes are made to converge towards it; but it is equally true that an object is always seen indistinctly—that the eye ceases to be adapted for the perception of it—when the object lies out of the line of the axis of vision, even though the lateral parts of the retina would otherwise perceive it distinctly. The false position of the axes of the eyes is attended with wrong adaptation, and the wrong adaptation with false position of the eyes; these changes of the eyes are to a certain extent necessarily attendant on each other. If, while we are regarding an object, the eyes be voluntarily adjusted for vision at a greater or less distance, the object appears double; that is to say, the axes of the eyes no longer converge towards it.

Fig. 89.

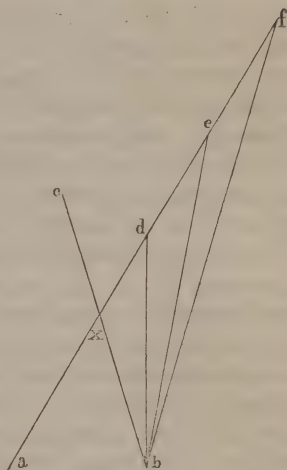


If, for example, *a* (fig. 89) be the object in which the axes of the eyes, A, B, meet, and we endeavour to see it indistinctly by inducing the internal adjustment for the perception of an imaginary object *d*, the eyes will immediately be directed towards *d*, so that *a* will be seen double, the image of it appearing to the eye A at *b*, to the eye B at *c*. The degree of indistinctness of these double images of *a* is dependent on the adjustment required for seeing distinctly the more distant object *d*. In proportion as the state of the eye, adapted for vision at *d*, is more similar to that adapted for seeing the object *a*, the double images will not only become more distinct, but will approach each other until, when the eye assumes the adjustment for *a*, they become one, the axes of the eyes then meeting at *a*. The double images in this experiment appertain to the opposite eyes,—*b*, to the eye A, and *c* to the opposite eye B. Hence the image *b* disappears when the eye A is closed, and the image *c* on the closure of the eye B. The double images always appear to be situated on the opposite side to the eye by which they are seen when an adjustment of the eye for a distance more remote than the object is assumed. If, on the other hand, *d* be the object to which the eyes were directed, and an effort is made to accommodate the eye to vision at an imaginary point *a*, which is nearer than *d*, the object *d* again not merely becomes indistinct, but is seen double; for the eyes, while they are adjusted for vision at *a*, are involuntarily moved so that their axes converge towards that point; *d* then appears on the outside

of the axis, $A b$, of the eye, A , and also on the outside of the axis, $B c$, of the other eye, B , and is consequently seen double and indistinct. In proportion to the indistinctness of the images does the distance between them increase. In this instance the double images lie upon the same side with the eye to which they belong: the image d , which belongs to the eye A , is seen on the same side of the object a as the eye A ; and the image d , which belongs to the eye B , on the same side of the object a as the eye B ; as is shown in the figure.

Even when one eye is closed, the adaptation to distance, and the movement of the axes of the eye-balls, give rise to each other reciprocally, and it is here that the connexion of these phenomena with each other may be best shown. Let a (in fig 90) represent the open eye, b the closed eye, and x, d, e , and f , objects situated at different distances in the axis of vision of the eye a . If, now the eye a be adjusted to see the point x distinctly, the axis of the covered eye b will be involuntarily directed towards x , and, if it be uncovered, the point x will be seen single at the convergence of the axes of the two eyes. If the eye a now pass from the refractive condition adapted for the object x , to

Fig. 90.



other states adapted for more distant objects in the line $a f$,—for example, for the objects e , or f ,—the covered eye will also be directed involuntarily towards e or f . On the other hand, by altering the inclination of the axes of vision, we are able to alter the state of adjustment of the eyes; and these changes are as completely simultaneous with each other, as the contraction and dilatation of the pupil with the convergence and parallelism of the axes of the eyes. If, for example, the axes of the eyes, a and b , are directed towards the imaginary point of space, d , and x consequently appears double, (one image being seen by the eye a in the direction $a f$, the other by the eye b in the direction $b c$,) the double images of x will also be indistinct, because the refractive power of the eye is accommodated to the distance d . If the axis of the eye a remain fixed in the direction $a f$, but that of the eye b be moved from the direction $b d$ to those of $b e$, $b f$, &c., so that the inclination of the axes of vision is diminished, the refractive condition of the eyes will also be modified in adaptation to the distances $e f$, &c., while the double

images of x will become more and more indistinct. The axis of one eye—namely, of that which is open,—may remain unmoved; but, if the axis of the closed eye be varied in direction, the internal adjustment to distance even of the open eye will be modified.*

In consequence of the power of modifying the refractive action of the eyes having a limit, while the optic axes are capable of any relative position with regard to each other, a want of accordance between the internal adjustment and the position of the eyes may happen when the objects are very distant; for instance, if one eye be fixed upon the moon while the other is covered by something held before it, the axis of the covered eye does not assume such a direction as to meet that of the other eye in the moon, though its refractive power is adapted for the distance from the eyes at which that object is situated; for, when the previously covered eye is left free, a second image of the moon is seen, but the two images soon become one from the error in the direction of the axes of the eyes being immediately corrected. This experiment, to which I first directed attention, afforded to one observer a different result. I mention it again, however, since in my case it always succeeded. The explanation of it offered by Treviranus is unsatisfactory.

From the foregoing facts it appears that change in the inclination of the axes of the eyes towards each other induces a change in the refractive power of the eye, by which this organ is accommodated to the distance of the object, even when one eye only, which is closed, alters its inclination towards the other, which is open. The same is the case with the motions of the iris: if one eye be fixed upon a given point, and the other eye closed, when the latter is moved, the size of the pupil even of the open eye undergoes a change proportionate to the degree of convergence of the two axes of vision, giving the appearance of a voluntary influence over the motions of the pupil (see page 684). The movement of the iris simultaneously with that of the axes of the eyes we have regarded as an associate or consensual movement, since it is observed to occur only when muscles supplied by the third or motor oculi nerve are in action, and that nerve is known to be the motor nerve of the iris, to which it sends filaments through the medium of the ciliary ganglion. In the same way the adjustment of the eye to vision at different distances may be an associate movement connected with the action of the muscles which draw the eye-ball inwards, and dependent either on an organic connexion in the nervous system, or on the influence of habit. The associate movement of the iris with the eye-balls can scarcely, however, be the result of habit.

* Compare Porterfield, *A Treatise on the Eye*; Edinb. 1759, v. i. p. 410: and Volkmann, *loc. cit.* p. 144. [See also Dr. Well's *Essay on Single Vision*, pp. 65 & 94.]

A slight influence upon the adaptation of the refractive power of the eye can be exerted by the will, without the direction of the axes of the eyes being necessarily changed; and this circumstance is itself a proof that the connexion between the two is not essential, and that the one is not the constant cause of the other. Plateau has stated, from observations made in his own person, that, by a voluntary effort, objects can be rendered indistinct through modification of the refractive power of the eyes, without any change in their position being induced. I had myself previously remarked that frequently, when a great effort was made, an object appeared to become indistinct without any double image being formed, though this appearance was only transient; but added that, in this case, though the double images were not seen in separate situations, they were both present, but in part placed one over the other. Experiments which I have since instituted lead me to agree entirely with Plateau in the observation that, intimately as the modification of the refractive power of the eye is connected with the alteration of the inclination of the axes of the eyes towards each other, yet with great practice the perception of an object upon which the eyes still remain fixed as before, may be rendered indistinct by the refractive power of the apparatus of vision being voluntarily modified so as to be adapted to another distance.

When the perception of an object is thus voluntarily rendered indistinct without the direction of the axes of vision being changed, the iris performs the usual motions, dilating when the eye is adapted for more distant vision, and *vice versâ*. This is an example of nearly perfect voluntary motion of the iris, inasmuch as here the motion is, at all events, not associated with any voluntary movement of the eye itself inwards and upwards.*

We perceive in this fact, as in all the phenomena previously described, the existence of an intimate connexion between the motions of the iris and the power of modifying the refractive action of the eye; but, nevertheless, we are not justified in ascribing to the motion of the iris even an indirect influence on the refractive power. It has been supposed that the motion of the iris may have an influence upon the ciliary body or processes, and through their medium upon the position of the lens, by virtue of the firm connexion of the ciliary body with the outer circumference of the posterior surface of the iris. This hypothesis, however, is easily refuted; for the movements of the iris may be excited by the stimulus of light independently of the will, and the same object appears to us equally distinct, whether it be illuminated with a bright light, when the pupil will be proportionately contracted, or the eye

* Müller's Archiv. 1837, p. cl.

screened from the action of light, when the pupil will be dilated.* It appears, therefore, most probable that the faculty of the eye which enables it to adjust itself to different distances depends on an organ which has certainly a tendency to act by consent with the iris, but yet is in a certain degree independent of it. Reasoning *per exclusionem*, it is certainly most probable that the ciliary body has this motor power, and this influence on the position of the lens, but we have no positive proof of its possessing contractility.

The self-adjusting faculty of the eye is, according to the observations both of Dr. Young and Volkmann, impaired by the extraction of the lens in the operation for cataract.

VI. *Of Myopia and Presbyopia, of the means of remedying these defects of vision, and of the use of glasses.*

Indistinctness of very near objects.—Action of diaphragms.—There is in every individual a point at which objects brought nearer and nearer to the eye can no longer be seen distinctly. Objects at the distance of from one to three inches, or less, from the eye, do not produce a distinct image on the retina, because the point at which the luminous rays emitted by them meet in a focus is in all persons situated behind that membrane. If the object held before the eye be small, it produces only a glimmering or cloud-like appearance, through which, though the object covers the middle of the pupil, more distant bodies are seen. The perception of distant objects through the indistinct image of one held near to the eye is intelligible when we recollect that, although those rays of the distant body which would pass through the centre of the pupil are intercepted, other rays will pass at the sides of the near object and enter the eye. Hence it is a necessary condition for seeing distant objects through the glimmer of a near one held close to the eye, that the latter be smaller than the pupil. It may indeed be very nearly as large as the pupil; for the peripheral rays of the cone of light from the more distant object will, in this case, by inflexion at the edges of the near body, still gain entrance into the eye and produce an image.

A distant object is also discerned by means of the rays passing through the circumference of the lens—the peripheral rays of the cone of light—when it is looked upon over the margin of another body held before it. It is a generally known fact that, if, while we are looking at a distant object, a second nearer object is interposed from the side, the more distant one appears to shift its place somewhat, and to become enlarged, as soon as the margin of the nearer object approaches it. This seems to be owing partly to the image being formed by rays which pass

* Compare Volkmann, loc. cit. p. 156.

through the circumference of the lens, and partly also to the inflexion of the light by the edge of the interposed body.

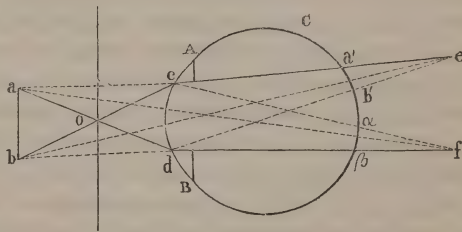
The glimmering cloud-like spectrum which small objects held very close to the eye produce in place of a distinct image, is larger in proportion to the size of the pupil; for, inasmuch as the spectrum representing each point of the object is a section of the cone of light sent by it through the pupil, each point of the object will be represented in a larger space on the retina according as the pupil is wider. The appearance produced by a small body, such as a needle held very near the eye, is the result of the simultaneous impression on the same parts of the retina of the spectra of all points of the object. These considerations enable us to account for some interesting phenomena. If a pin be held at such a distance from the eye that it still produces an image, but one which is indistinct and hazy, this hazy image appears larger or smaller according as the eye is shaded or subjected to a strong light; in other words, according as the iris dilates or contracts. This is an excellent mode of observing the motion of the iris in one's own person by means of a phenomenon of vision.

Under certain conditions, however, objects held close to the eye may be seen distinctly, and then appear much enlarged, though no glasses to aid the eye be used. This happens, namely, when very near objects are viewed through a minute opening in a card. M. Henle, who has investigated this phenomenon, directed my attention to it and to its causes. It was known to Lecat, Monro, and Priestley. If we hold close to the eye the printed leaf of a book, we are unable to distinguish a single letter; but if, when it is at the same distance, we look at it through a pin-hole in a card placed close to the eye, we immediately perceive very clearly both the letters and their white interspaces. It might be imagined that the cause of the distinct vision in this instance was that the central rays were isolated from the peripheral rays of the cones of light by the small size of the opening, and that, on account of the greater density of the nucleus of the lens of the eye, they are brought sooner to a focus, though in a lens of equal density throughout the central rays meet at a focus later than the peripheral rays; but, according to this view, the size of the object should not be increased. It may be said that the increase of size is merely apparent, and owing to the circumstance that, when the print is viewed closely without the interposition of the card, the nucleus only of the hazy image is taken cognizance of, and not its whole dimensions; but this objection is easily refuted by viewing the object simultaneously with both eyes, one with the perforated card, the other without it, and comparing the images. It is then seen that the white spaces between the letters, as well as the print itself, appear larger with the interposed card; three lines of one image being contained in the same space as two of the image seen with the

other eye. Lecat* and Priestley† attribute the phenomenon to the inflexion of the rays at the margin of the opening in the card; the first of these writers referring for confirmation of his opinion to the change which the outline of a distant body suffers when the edge of a rod is interposed between it and the eye. The distant body appears, namely, to expand when the rod is moved into the line of the axis of vision. The distinctness of very near objects seen through an opening in a card may certainly be explained on the principle of inflexion, or more correctly diffraction, by which light is bent from its course in two directions. According to this view, the more exterior of the rays inflected at the margin of the opening in the card meet at a focus still farther behind the retina even than the rays of near bodies otherwise do; while the more internal of the inflected rays are brought to a focus sooner, and consequently meet no longer behind the retina, but upon it; and hence the distinctness and brightness of the image, notwithstanding the small quantity of the light engaged in producing it. The increase of size of the image is, however, not easily intelligible from this theory.

Another explanation of the phenomenon is proposed by Henle. Let ab (fig. 91) be the body held close to the eye, AB the refractive media, C the retina. The cone of light emitted by the point b is concentrated to a focus

Fig. 91.



at e ; that from the point a , at f . The straight line, be , will be the direction of the central ray of the cone of light emitted by the point b ; the straight line, af , that of the central ray of the cone of light from the point a : the focal points, e and f , lie behind the retina on account of the too great proximity of the object to the eye. The point b , therefore, is seen as a broad spectrum, $a'b'$; the point a as a similar spectrum, $a\beta$. If now the card, with the small opening o , be interposed between the object and the eye, the rays of the two cones of light are partially intercepted, so that the bundles of rays, bc and ad , alone reach the eye through the opening o . The image of b is consequently seen distinctly at a' , that of a at β . Inflexion of the rays may contribute to render the image of the object distinct by causing the rays of each pencil of light which passes through the opening in the card to fall simultaneously upon a single point of the retina.

* *Traité des Sens*, p. 305.

† *Geschichte der Optik*. p. 391. *History of Light and Colours*; Lond. 1772.

The increased size of the image is owing to the rays α and β , which excite the sensation, being further distant from each other than the central rays of the cones of light would be.

“*Myopia*,” *near-sight*; and “*Presbyopia*,” *far-sight*. — *Spectacles and Optometers*. — Many persons have not the power of accommodating their eye to vision at different distances, or have it in so slight a degree as to distinguish objects at a certain distance only; such persons are said to be either short-sighted or long-sighted. To individuals in this condition it is, of course, impossible to prove that the eye has the faculty of adjustment to distance; and this may have been the cause of the scepticism of Treviranus and others. Near-sightedness is most frequently observed in the middle period of life. Long-sightedness is more common in old age. The cause of these defects of vision is very often supposed to lie in the refracting media of the eye, as in the form of the cornea; and the cornea is, in fact, less convex in old age than in youth; but the convexity of the cornea is greatest in childhood, and, nevertheless, as Volkmann remarks, children are not frequently subjects of “near-sight.” Myopia and presbyopia may with more reason be attributed, as regards their immediate cause, to want of the power of adjustment, or to great feebleness of this muscular act. With such a condition the eye would necessarily see objects distinctly at that distance only to which the form of its refractive media is best adapted. A strong proof of imperfection, or loss, of the power of adjustment being the cause of myopia and presbyopia, is the circumstance that short-sightedness may be acquired merely by habitually using the eye for the perception of near objects only, and neglecting distant vision. Thus, children become short-sighted from accustoming themselves to read or write with the face too close to the paper. The constant use of the microscope may give rise to short-sightedness, and often does induce it as a transient condition lasting a few hours. The wearing of spectacles also is injurious in this respect, since they disuse the eye to self-adjustment for distinct vision at different distances.

Sometimes the two eyes differ in their mean refractive power, though the pupils do not in these cases always present a corresponding difference in size. This unequal action of the eyes may also be acquired by employing one of them especially in the perception of near objects, as in the use of the microscope, &c. This inequality of the refractive power of the eyes is produced most rapidly, however, by narcotizing one eye by means of a few drops of solution of the extract of belladonna (see page 1144). In all these cases, the eyes, though differing in their mean refractive condition, may both retain the faculty of accommodation to different distances; the voluntary adjustment of one eye influences the other also, but yet the condition of the two remains unequal. Thus, if we express by two series of numbers the progressive change

in the state of refractive power in the two eyes respectively, and the adjustment of the eye A be represented by 3, that of the eye B may be expressed by 1; and if the refractive power of the eye A becomes 5, that of the eye B will become 3. With a state of adjustment expressed by 1, the eye A sees distant objects distinctly, while the eye B discerns nothing. Within a certain limit both eyes, perhaps, may see distinctly when used simultaneously, since the indistinct image of the one eye may not disturb the perception of the other eye, and the two images are seen in the same position in the field of vision as one image; but the eye which was defective in the vision of distant objects has greater capability for close vision.

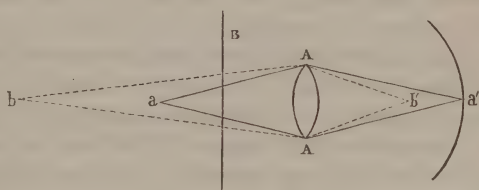
1	
2	
3	.. 1
4	.. 2
5	.. 3
6	.. 4
7	.. 5
8	.. 6
9	.. 7
10	.. 8
	9
	10
	11
	12
A	B

The eye A has, perhaps, at 10 reached the limit of its sphere of adaptation; while the other eye, B, sees distinctly at 11 and 12. Inequality of the refractive power of the eyes is in many persons the original source of squinting, the eye of the most useful medium focus being employed by preference, while the other is not attended to, so that the image formed in it becomes no source of confusion. Even when eyes of equal refractive power are fixed upon the same object, one being furnished with an eye-glass, the other without any, the axes of the eyes do not meet in the object, which is apt to be seen double; this is also the case when spectacles of unequal power are used. The double images are still farther distant from each other, owing to the axes of the eyes not being both directed towards the object, when the refractive power of one of the eyes has been modified by the action of belladonna; in which case, while an object at a certain distance is seen distinctly by one eye, the image of the other is seen floating indistinct and hazy by its side. The cause of this want of coincidence of the images of the two eyes is intelligible from the considerations entered into, at page 1146, relative to the connexion between the refractive state of the eye and the position of the axes of the eye-balls. How it is that the image of an object depicted in the weaker eye does not disturb vision will be explained hereafter, when we come to state the facts which prove the existence of a kind of antagonism between the fields of vision of the two eyes, like that between the two scales of a balance, owing to the intensity of nervous action being greater sometimes in one, sometimes in the other eye.

We may now, in a few words, explain the action of spectacles in aiding vision in persons labouring under myopia and presbyopia. The presbyopic, or long-sighted eye, is aided by a convex glass; the myopic, or short-sighted, by a concave glass. In the long-sighted eye, rays from distant objects are brought to a focus upon the retina; but the rays from objects less distant, or very close to the eye, not being made

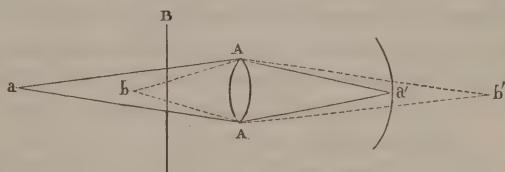
to converge so rapidly, meet behind the retina. A convex glass corrects this defect by causing the rays emitted by near objects to intersect each other at a point nearer the lens, — namely, in the retina itself. In the short-sighted eye the reverse condition subsists. The rays from near objects here meet in the retina, and produce a distinct image; but the rays of distant objects, which are more easily brought to a focus than those of near objects, meet before the retina, and form undefined spectra upon it. The concave glass corrects this by causing the rays to become more divergent, and therefore less readily concentrated by the eye to a focus, which is thus made to fall upon the retina. Figure 92 represents the direction of the rays in a short-sighted eye; A A being the refracting media of the eye. The rays emitted by a very near object, *a*, meet upon the retina at *a'*; those of a distant object, *b*, on the other hand, meet at a focus sooner, namely at *b'*. A concave glass at B causes the rays A *b'*, A *b*, to assume the direction A *a'*, A *a'*. A distant object, *b*, can therefore be seen distinctly at *a'* only by the use of the concave glass.

Fig. 92.



Again, let A A (fig. 93) represent the refractive media of a far-sighted eye; the luminous rays from a distant object, *a*, will, in this case, be concentrated to a focus at *a'*, that is,

Fig. 93.



upon the retina. The image of the near object, *b*, will, on the contrary, be formed behind the retina at *b'*. A convex glass at B will here cause the rays of the near object to be brought to a focus more rapidly, so as to form the image upon the retina at *a'*, instead of behind it at *b'*.

The use of the optometer to determine the mean distance of vision for which the eye of any individual is adapted, is founded upon the experiment of Scheiner, detailed at page 1139. It consists in ascertaining the distance from the eye at which a small object viewed with one eye through two openings in a card, separated by a less distance than the diameter of the pupil, appears single; or the distance

from the eye at which the double images of a thread, viewed without effort through two openings in a card, cross each other or unite to one image.—(Young's Optometer.) The distance thus ascertained is the mean length of vision of the eye. Before and behind this, an object viewed through the two openings in the card appears double; that is to say, its image falls either before or behind the retina. The application, however, of this method is always very imperfect, on account of the diffraction of the rays at the margins of the small openings in the card.

Influence of convex lenses upon the distance of distinct vision.—We have next to consider the action of glasses which increase the size of the image by altering the distance of distinct vision. The simplest kind of glass which has this effect is the common lens, or simple microscope. If a small object be brought very near the eye, it appears very large, but is wholly indistinct, because the point towards which the rays from it are made to converge lies behind the retina. The action of a lens interposed between the object and the eye is to shorten the focal distance of the image. If the lens be properly placed, so that the image falls upon the retina, all the details of its form are seen distinctly, while it appears of the same magnitude as when held close to the eye without the lens. In this case the increase of size is the result of the close approximation of the object; and the lens merely gives distinctness, which the image of so near an object would not otherwise have. In the telescope and compound microscope the image is formed, not in the eye itself, but in front of it. The rays meeting to form the image, not being received there by any opaque surface, diverge again from this point, in the same way as if the object from which they originally radiated were there situated. On this condition depend both the increase of size and the distinctness of the image in the eye; for an image near the eye is seen under a greater angle than the more distant object. And if the image occupies the situation of distinct vision at eight inches, it is not only increased in size, but has the distinctness of objects generally viewed with the naked eye at that distance. Telescopes serve to increase in size, and render distinct, the image of very distant objects; microscopes to enlarge, and render distinct, the image of near objects. The number of glasses employed in these instruments is very various. A second glass, placed behind the first, may either modify the image and its situation, or, if the image is already formed by the first glass before the rays traverse the second, this image stands in the relation of an object to the second glass. The image formed by the second glass may be still further modified by a third glass, or may become an object to it. The glass which receives the rays of light directly from the object itself is called the "object glass;" the glass next to the eye is the "eye-piece," or

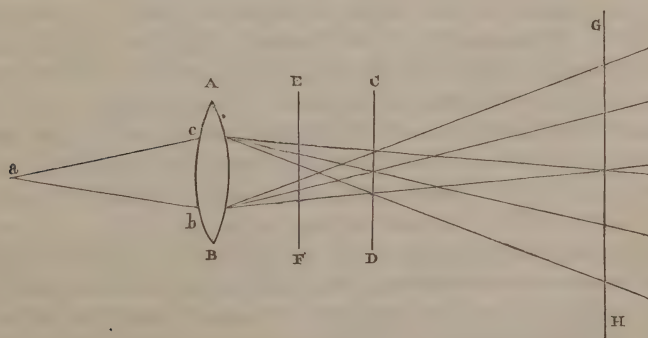
“ocular.” In the microscope, the image formed by one or more lenses is viewed by means of the ocular, just as an object is viewed with a simple lens. The brightness of the image depends on the quantity of light which the object-glass receives from the object, or which, in the microscope, is thrown by artificial illumination upon the object. According as the quantity of light which goes to form the image in the telescope or microscope is greater or less than that which the naked eye receives from the object, will the image of the object be more or less vivid than when seen without the instrument. The image of objects viewed with the telescope is brighter than the object appears when viewed with the naked eye; because the object-glass of the telescope receives from the object, and applies to the formation of the image, more light than the pupil of the naked eye can admit.

V. *Of the chromatic and achromatic properties of the eye.**

a. *Chromatic lenses.*—Although the rays from a luminous object are by the refractive power of a lens concentrated so as to form a distinct image upon any surface, when spherical aberration is avoided, yet the image is not perfect unless the rays of light are homogeneous, that is, of one simple colour; for, even though spherical aberration be avoided, it is quite impossible, without further means, to bring the heterogeneous rays of white or mixed light to one focal point, since the different-coloured rays of white light have different degrees of refrangibility, and, therefore, with the same refracting medium have a different focal distance.

If *a* (fig. 94) be the luminous point, A B the lens, and *a b c* a cone of light containing rays of different colours, these rays will be refracted in different degrees; the violet rays, for example, which have the greatest refrangibility, will meet at a focus first, the yellow

Fig. 94.



* J. Müller, *Physiol. des Gesichtsinnes*, pp. 195, 414.—Tourtual, *Die Chromasie des Auges*; Meckel's Archiv, 1830, p. 129.

later, and the red last. In place of a colourless, luminous point, therefore, there will be at the part where the light is most concentrated, at C D, a coloured spectrum, of which the centre will be white, on account of the coloured rays being there mingled; while the borders will be purple, owing to the presence of the red and violet rays without the yellow. The image will appear more coloured if the surface which receives it be placed before or behind the mean focal distance, as at E F, or G H. At E F, for example, the red rays, which are there most external and unmixed with other rays, form a fringe of red light; the most external of the yellow, mingled with red rays only, form a fringe of orange within the red, and around the colourless centre in which all the different-coloured rays are intermingled. At G H the violet rays will form the outer fringe; within this will be the blue, which are next to the violet in refrangibility; and the centre will be white.

The image formed by a convex lens is at the proper focus very slightly coloured: the outline of a white image received upon a dark ground has merely a margin of purple, which is scarcely perceptible; but, in proportion as the surface which receives the image is moved from the focal point, the more marked becomes the fringe of colours, in addition to the increasing indistinctness of the image formed by the white light itself.*

b. Achromatic lenses.—The dispersion of the coloured rays by a prism is counteracted by a second prism of the same refractive and the same dispersive power. Two prisms conjoined form a refracting medium with parallel surfaces, from which the rays of light transmitted through it will issue at the same angle as they entered, just as in passing through a plane plate of glass. Dollond, however, discovered that the dispersive power of media is not always proportionate to their refractive power; and that there are media which have a strong refractive action on light, but little dispersive influence. Flint-glass refracts light more strongly than crown-glass, but its excess of dispersive power is still greater. This led to the construction of achromatic prisms by the combination of prisms of unequal refractive and dispersive power. A prism of crown-glass, and one of flint-glass of the same refractive angle, united, bend the parallel rays which entered them out of their direction; and instead of transmitting them colourless, as two prisms of crown-glass of the same angle would do, disperse them so as to form a coloured spectrum, owing to the excess of dispersive power of the flint-glass. If, now, the refracting angle of the prism of flint-glass be so far diminished that both prisms disperse the light equally, the dispersive action of one neutralizes that of the other, and the rays are transmitted colourless; while the simple refraction remains, on account of the different angle of the two

* See Kunzek, *Die Lehre vom Lichte*, p. 157; and Tourtual, *loc. cit.*

prisms. An achromatic prism is formed by combining a crown-glass prism of a refracting angle of 30° with a prism of flint-glass having a refracting angle of 19° only. We may hence conceive the principle of the construction of achromatic double lenses which reciprocally correct each other's dispersive action. The most perfect achromatic doublet, however, does not prevent the production of colours when the image is not received at the proper focal distance; and, in the best telescope, objects appear surrounded with coloured fringes when the ocular is moved beyond the limits of distinct vision.*

c. Achromatic property of the eye.—The human eye is achromatic as long as the image is received at its focal distance upon the retina, or as long as the eye adapts itself to the different distances of objects. The cause of this achromatic property cannot with certainty be determined, although it is easy to show that the optical structure of the eye may very possibly give this property. The refractive media of the eye are of unequal refractive power, both as regards their convexities and their chemical constitution. The lens has two unequally convex surfaces, and the cornea and aqueous humour form a refracting medium of unequal chemical constitution. The cornea and aqueous humour taken together form a concavo-convex lens, the refractive power of which is different from that of the crystalline lens. The dispersive power of these two refracting media may perhaps be disproportionate to their refractive power, and this may be the source of the achromatic property of the eye. The achromatic and aplanatic double object-glasses of Sir J. Herschell have some distant resemblance in form and composition to the refracting media of the eye. They consist of a biconvex lens of crown-glass, the radii of whose convexities are of unequal length, and of which the more convex surface is turned outwards towards the object, and of a concavo-convex lens of flint-glass, the concave side of which is turned towards the lens of crown-glass, while its convex side is towards the eye.

d. Chromatic property of the eye.—It is an error to regard the human eye as perfectly achromatic. Whenever the image does not fall at its proper focal distance upon the retina, a more or less distinct appearance of colours is produced. The dioptric fringes of colours produced in our eye by its refractive media, and capable of being excited to a certain extent at will, appear to have been first observed by Scheiner.† To

* Kunzek, *Lehre vom Lichte*, pp. 172—177.

† Extended observations on the subject of these phenomena will be found in Comparetti's *Observationes dioptricæ et anatomicæ comparatæ de color. apparent. visu et oculo*; Patav. 1798, 4: in an article on the production of colours in the eye, in Schweigger's *Journal*, Bd. 16: in my work, *Zur Physiol. des Gesichts-sinnes*; Leipz. 1826, pp. 194—204: and in Tourtual's excellent paper in *Meckel's Archiv.* for 1830.

observe these phenomena in one's own person when the eye is in a healthy state, white objects upon a black ground, or black upon a white ground, must be held before the eyes while they are adjusted for nearer or more distant vision; the objects will then appear indistinct and surrounded with fringes of colours, and two images of each object will be seen, the cause of which will afterwards be explained. In proportion as the axes of the eyes deviate in their direction from that proper for distinct vision of the objects, the further distant do the double images appear from each other. The more indistinct the images, the more marked become the coloured fringes. At the commencement of the experiment they are not perceptible; but, by practice and attention, the narrowest line of colour around the image can be recognised. The image of an object can most easily be rendered indistinct at will by directing the axes of the eyes towards some body or ideal point nearer or more distant than it, and hence the coloured fringes are most readily perceived in this manner. With practice, however, it becomes possible to produce indistinct vision of an object with one eye only, while the other is closed, by causing it to adapt its refractive power to nearer or more distant vision. By this method coloured fringes may be seen with one eye, consequently without double images of the object being produced. The following are the results of my own observations:

1. If we look upon a white space on a black ground with one eye, adapting the refractive power of the eye to a more distant point than the object, the latter—that is, the white spot—will appear indistinct, and as if surrounded with a delicate and narrow fringe of colours passing from the white to the black ground through violet, blue, yellow, and red. Generally the blue and yellow have alone any degree of distinctness.

2. If we look upon the same object, and then adapt the refractive power of our eye to the perception of an imaginary object nearer to the eye, the coloured fringe of the image will present the same succession of colours—red, yellow, blue, and violet, but in the reverse order; the violet and blue are now nearer to the black, and the red and yellow next to the white.

When the vision of an object is rendered indistinct while both eyes are open, and two images are consequently seen, the colours in the surrounding fringes have the same arrangement as in the first case just described, if the axes of the eyes are made to converge to a point behind the object; while their order of succession is reversed as in the second case, if the axes of the eyes meet in front of the object.

The frames of the window also appear fringed with very vivid colours when we gaze at distant objects through it; or if, while looking at the window, we fix our eyes upon a nearer object, as the finger held before them.

The phenomena of coloured fringes dependent on dispersion of the coloured rays by the refractive media of the eye, are apt to become complicated with the accidental colours of the spectrum left by the long impression of an object upon the retina, this spectrum becoming manifest on a slight lateral movement of the eye. The "subjective" spectrum left by a white spot upon a dark ground is grey; that of a black spot on a white ground, white; that of a coloured spot, of the opposite complementary colour. While the eye is fixed on the object, the real image covers the spectrum; but, if the eye be slightly moved to the side, the margin of the physiological spectrum is perceived at the edge of the real image. The luminous borders or fringes arising thus are seen on that side of the image towards which the eye moves, and must be distinguished from the dioptric fringes of colour, which have their source not in an affection of the retina, but in the refractive media of the eye. Comparetti has described these two phenomena combined. It is quite an error to ascribe the dioptric coloured fringes of objects to an affection of the retina, as is done in some pathological works. When they occur as symptoms of disease, they are not a consequence of any change in the act of vision, but of an affection of the self-adjusting faculty of the eye by which it naturally adapts itself to vision at different distances. Many persons complain of seeing coloured fringes while their power of vision is otherwise perfect,—when there is no tendency to morbid changes in the retina, or to amblyopia or amaurosis. We have an instance of this phenomenon also in the red borders which surround the letters of print, when the adjusting power of the eyes is paralysed as a consequence of passion, of mental exertion, or inclination to sleep, &c. The coloured fringes are very evident also when the faculty of the eye to accommodate itself to distinct vision at different distances is suspended by the action of belladonna.*

The dioptric fringes of colours arising from refraction within the eye must not be confounded with the real coloured halos of luminous objects.

* See my work, *Zur Physiol. des Gesichts-sinnes*.

CHAPTER III.

OF THE ACTION OF THE RETINA, OPTIC NERVE, AND SENSORIUM IN VISION.

ALL the phenomena investigated in the preceding chapter are explicable by reference to the structure of the eye as an optical instrument,—that is, by the form and arrangement of the transparent media in front of the retina. There are a great number of other phenomena, however, of which the structure of these parts affords no explanation, but which are the results of vital properties of the retina, and of the co-operation of the sensorium in the act of vision. To these belong not merely the act of sensation itself, and the perception of the changes produced in the retina, as light and colours, but also the conversion of the mere images depicted in the retina into ideas of an extended field of vision,—of proximity and distance,—of the solidity (in the geometrical sense) and size of objects. To this class of phenomena belong also the effects of the reciprocal action of different parts of the sensitive apparatus on each other, and many phenomena in the retina either not excited by light at all, or not by its immediate action. These different phenomena will be treated of under the following heads: 1. Of the action of the retina generally, and of the co-operation of the sensorium in vision. 2. Of ocular spectra. 3. Of the reciprocal influence of different parts of the retina upon each other. 4. Of the simultaneous action of the two eyes. 5. Of the subjective phenomena of vision.

1. *Of the action of the retina generally considered, and of the co-operation of the sensorium in vision.*

Action of the retina and sensorium.—It has been shown already, in the Preliminary considerations on the Physiology of the Senses, that the retina is not a mere conductor of external impressions, but itself reacts against these impressions. Light and colour are actions of the retina, and of its nervous prolongations to the brain. The kind of colour and luminous image perceived depends on the kind of external impression. With this property of the retina, by virtue of which it becomes when irritated the seat of the sensations of colour and light we are so well acquainted, that we found upon it all inquiries concerning vision. The vibrations of a fluid existing in all space, the ether, when of a certain rapidity, produce in the retina the sensation of a certain colour; when of a different degree of rapidity, that of another colour; these colours or sensations being modes of reaction of the retina. The simultaneous impression of undulations of different rapidity upon the same points of the retina excites the sensation

of white light. These same sensations of colours and light may, however, be produced, without the agency of the vibrations of an ether, by mere irritation of the retina by means of electricity or mechanical pressure.

If it be the change produced in the retina which we perceive in vision, we may with equal correctness say that in the act of vision the retina feels itself in a particular state, or that the sensorium perceives the retina in a particular condition. The condition of repose of the retina is the cause of the appearance of darkness before the eyes; the active state of the retina is the cause of the sensation of the illuminated field of vision. Under certain circumstances we see our own retina, and separate parts of it, when no images are produced in it by external objects. Besides the spectra produced by pressure and electricity, we have an instance of this in the following interesting phenomenon first observed by Purkinje:—If, in a room otherwise dark, a lighted candle be moved to and fro, or in a circle, at the distance of six inches before the eyes, we perceive, after a short time, a dark arborescent figure ramifying over the whole field of vision; this appearance is produced by the vasa centralia distributed over the retina, or by the parts of the retina covered by those vessels. There are, properly speaking, two arborescent figures, the trunks of which are not coincident, but on the contrary, arise in the right and left divisions of the field, and immediately take opposite directions. One trunk belongs to each eye, but their branches intersect each other in the common field of vision. The explanation of this phenomenon is as follows:—By the movement of the candle to and fro, the light is made to act on the whole extent of the retina, and all parts of the membrane which are not immediately covered by the vasa centralia are feebly illuminated; those parts, on the contrary, which are covered by those vessels cannot be acted on by the light, and are perceived, therefore, as dark arborescent figures. In most persons this experiment succeeds readily; but in some individuals the phenomenon is produced with difficulty, or not at all. The figures of the vessels appear to lie before the eyes, and to be suspended in the field of vision. We have here a distinct demonstration of the axiom, that in vision we perceive merely certain states of the retina, and that the retina is itself the field of vision,—dark in the unexcited, illuminated in the excited condition.

One of the most difficult problems in physiology is that relative to the respective influence of the retina and sensorium in vision. This department of the physiology of the senses may be correctly styled the metaphysical, since we are at the present time totally destitute of any empirical means of elucidating it. The question to be determined is the following:—Where is the state of the retina perceived; in the retina itself, or in the brain?

If the states of the minute portions of the retina are first perceived in

the brain, they must be communicated along the optic nerve to the brain in the same order in which the affected parts of the retina stand in relation to each other; and to each ultimate sentient division of the retina there must be a correspondent nervous fibre in the optic nerve. Anatomical facts by no means accord with this view. A comparison of the thickness of the optic nerve with the extension of the retina is little favourable to the existence of such a relation between them. The number of nervous fibres in the optic nerve appears to be much less than the number of the papillæ on the surface of the retina. If, then, such a relation between the retina and optic nerve subsists, we can only suppose that the so-called primitive fibres of that nerve contain much more minute and numerous elementary parts. It must, however, be remembered that the sensibility of the retina is acute at its central part only; and if we assume that at this part the ends of the nervous fibres are aggregated closely together, while in the other parts of the membrane they are separated by intervals increasing in size from the centre outwards, we dispose of a part of the difficulty. The sensibility of the middle portion of the retina is in fact as acute, and that of the lateral parts as obtuse, as we might imagine them to be, if in the centre of the retina separate minute divisions of the image corresponded to the extremities of separate fibres, while at the sides one nervous fibre was subjected in some extent of its length to the impressions of many minute points of the image. It would be of especial importance in reference to this question, to know in what relation the papillæ of the retina, observed by Treviranus, stand to the subjacent fibrous layer; whether in fact each nervous fibre does, as he states, bend and become continuous with a single papilla, or whether it corresponds to a complete series of papillæ. But if the perception of locality takes place in the brain, how can the changes in separate successive portions of the length of a fibre be communicated to the sensorium? If we become conscious of sensations only by their being communicated to the brain by the ends of the separate nervous fibres, then the affections which aliquot parts of the length of one fibre have suffered will be perceived by the brain only at one point. If, on the other hand, the sensation of distinct locality be perceived in the aliquot parts of the length of a fibre itself, the mind must be in action in each portion of the length of such fibre; to which supposition, as applied to spinal nerves, the observations relative to the sensations in amputated limbs are opposed. This difficulty might be removed by supposing that the nerves of the higher senses have a more close participation in the action of the mind than other nerves; that the action of mind extends to the extremities of the nervous fibres in the retina; that, in fact, the nerves of the higher senses are merely prolongations of the sensorium. In the present state of our knowledge it is utterly impossible to solve this problem.

However the above question may be decided, it is at all events certain that, even after the retina and external portion of the optic nerve are lost, the internal or central portion of the organ of vision is capable of exciting not merely sensations of light, but also the same ideas of a field of vision in which images are perceived, as when the retina is present. The remarkable phenomena observed by Lincke are an instance of this. A patient, in whom an eye affected with fungoid disease had been extirpated, perceived on the day following the operation, while the sound eye was closed, different images,—such as lights, circles of fire, dancing figures, &c.—floating in front of the orbit from which the eye had been removed.* Similar phenomena have been several times observed in persons totally blind.† These facts would seem to prove that the affections of the fibres of the optic nerve are communicated to the brain before they give rise to the sensation of a field of vision; and, in that case, we must admit that each minute division of the retina is represented in the sensorium by a corresponding nervous fibre, though this cannot be demonstrated anatomically.

The mode of action of the peripheral and central parts of the apparatus of vision upon each other is, therefore, at present, involved in much obscurity; and we must rest satisfied with a knowledge of the fact, that the order of the images in the field of vision depends upon the relative position of the affected parts of the retina.

Ideal size of the field of vision.—The actual size of the field of vision depends on the extent of the retina, for only so many images can be seen at any one time as can occupy the retina at the same time; and thus considered the retina, of which the affections are perceived by the sensorium, is itself the field of vision. But to the mind of the individual the size of the field of vision has no determinate limits; sometimes it appears very small, at another time very large; for the mind projects the images on the retina towards the exterior, the cause of which will be explained hereafter. Hence the mental field of vision is very small when the sphere of the action of the mind is limited by impediments near the eye; on the contrary, it is very extensive when the projection of the images on the retina towards the exterior by the influence of the mind is not impeded. The mental field of vision is very small when we look into a hollow body of small capacity held before the eyes; it is large when we look out upon a landscape through a small opening; it is more extensive when we look at the landscape through a window; and most so when our view is unconfined by any near object. In all these cases the idea which we receive of the size of the field of vision is very different, and, nevertheless, its absolute size is in all the same, it being dependent on the extent of the retina; for,

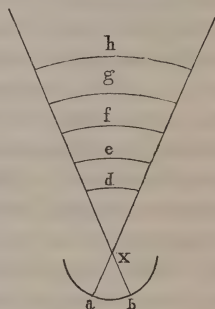
* Lincke, *De Fungo Medullari*; Lips. 1834.

† See my tract, *Über die Phantastischen Gesichterscheinerungen*; Coblenz, 1826.

as was before said, we can not see at one time more than the extent of the retina is capable of containing. Nevertheless, although in looking upon a landscape through an opening, the whole image of the scene is not larger than the circumference of the opening through which it is viewed, and occupies the same space upon the retina; yet the idea conceived of it is extremely different. Hence it follows that the mind is constantly co-operating in the acts of vision, so that at last it becomes difficult to say what belongs to mere sensation, and what to the influence of the mind. In adult age it would only be by abstracting the action of the mind from the process of vision that we could obtain the mere sensation of vision, as it is perceived possibly in the new-born child; for the child which has as yet no idea of proximity and distance, would necessarily recognise no difference in the size of the field of vision, whether it looked into a tube closed at one end, or through an open one upon an extensive landscape. This consideration leads us also to the conclusion, that the simple perception of the images of objects must be an original faculty, quite independent of the ideas derived from them.

Every object seen under the same angle, $a x b$ (fig. 95), has an image of the same size, $a b$, upon the retina; the objects d , e , f , g , h , which are of very different size, but are situated at different distances, are seen under the same angle, and therefore produce images of the same size upon the retina: and, nevertheless, these images appear to the mind of very unequal size when the ideas of distance and proximity come into play; for, from the image $a b$, the mind forms the conception of a visual space extending to d , e , f , g , or h , and of

Fig. 95.



an object of the size which that represented by the image on the retina appears to have when viewed close to the eye, or under the most usual circumstances. A landscape depicted on the retina, as $a b$, and viewed under the angle $a x b$, is therefore conceived by the mind to have an extent of two miles perhaps, if we know that its extent is such, or if we infer it to be so from the number of known objects seen at the same time. And in the same way that the images of several different objects, viewed under the same angle, thus appear to the mind to have a different size in the field of vision, so the whole field of vision, which has always the same absolute size, is interpreted by the mind as of extremely various extent; and, for this reason also, the image viewed in the camera obscura is regarded as a real landscape,—

as the true field of vision,—although only a small image depicted upon paper. The same mental process gives rise to the idea of depth in the field of vision; this idea being fixed in our mind principally by the circumstance that, as we ourselves move forwards, different images in succession become depicted on our retina, so that we seem to pass between these images, which to the mind is the same thing as passing between the objects themselves.

It is evident, therefore, that the field of vision conceived by our mind is extremely variable, while the field of the simple sensation of vision is entirely dependent on the extent of the retina, or of the central parts of the apparatus of vision in the brain. This latter field of vision is represented most nearly by sensations excited in the retina independently of any object which can call the mind to action,—for instance, by the sensation of darkness before the closed eyes, or by the sensation of light before the eyes when the lids are closed, but the light shines through them. In these cases the field of vision seems to be immediately before or in the eyes; but, as soon as the idea of an object already seen can associate itself with the sensation, the mental faculty of “projection” towards the exterior comes into play, and the size attributed to the object which excites the sensation depends on the former experience of the individual. Hence the difference in the statements of different persons respecting the size and apparent distance from the eye of the vessels of the retina perceived in Purkinje’s experiment.

The action of the sense of vision in relation to external objects is, therefore, quite different from that of the sense of touch. The objects of the latter sense are immediately present to it; and our own body, with which they come into contact, is the measure of their size. The part of a table touched by the hand appears as large as the part of the hand receiving an impression from it, for a part of our body in which a sensation is excited is here the measure by which we judge of the magnitude of the object. The part of the hand brought into contact with the table forms a part of the whole sensitive surface, and the part of the table touched appears as large as the part of the hand which touches it is in proportion to our whole body; the power of distinguishing the different parts of our body depending on the possibility of distinguishing in the sensorium the nervous fibres coming from different parts. In the sense of vision, on the contrary, the images of objects are mere fractions of the objects themselves, realized upon the retina, the extent of which remains constantly the same. But the imagination which analyses the sensations of vision, invests the images of objects together with the whole field of vision in the retina, with very varying dimensions; the relative size of the images in proportion to the whole

field of vision, or of the affected parts of the retina to the whole retina, alone remaining unaltered.

Volkmann remarks,* that the retina is in no case sensible of its own extension, and that even the sense of touch does not inform us of the definite extent and figure of the surface of our body. He founds this opinion on the facts observed by E. H. Weber, which have showed that the distance between two points is perceived very differently at different parts of the surface (see page 700). Volkmann, therefore, supposes that the skin, in measuring the size of objects, takes as unity the extent of the small division of its own surface capable of distinguishing distance. If we call this measure of unity x , an inch will to the point of the fingers be $12x$, to the middle of the arm $1x$; for every spot of the skin touched by an object will ascribe to that object a size which equals so many times x as it contains parts capable of distinguishing two points touching it from each other. According to this view, when I touch the middle of my arm with the point of the finger, the part of my finger which comes into contact with my arm should feel twelve times as large as the corresponding part of the arm. Volkmann applies this view to the retina also; and supposes that it also, in estimating the size of objects, takes as unity the most minute space capable of being distinguished by vision. The phenomena observed by Professor Weber are explicable, however, in another way, namely, as the result of the mingling or radiation of sensations (see page 697).

Relation of the sense of vision to the external world.—We have next to inquire how the action of the sense of vision in relation to the external world is first established. Several physiologists—as, Tourtual, Volkmann, and Bartels—suppose the interpretation of the sensations of the retina as objects forming part of the exterior world to be a faculty of the sense of vision itself. But what, in the first place, constitutes the external world? Since in the first acts of vision the image of the individual's own body cannot be distinguished from those of other bodies the referring of the sensations of vision to something external can be nothing else than the discrimination between the sensations of vision and the subject of them,—between the sensations and the sentient “self.” It is by the operations of the judgment that the objects of vision are recognised as exterior to the body of the individual; this has been already explained and illustrated in the Preliminary Considerations on the Physiology of the Senses. It is said that the new-born infant perceives from the first that the objects of vision are external to its body and to its eye; but the infant recognises neither its own eye nor its body in the form of sensations of vision, and only learns by experience which of the

* Beiträge zur Physiol. d. Gesichts-sinnes, Leipz. 1836.

images which it sees is its own body. We can, therefore, only say that the new-born infant distinguishes the sensations from the sentient "self," and in this sense only does it perceive the sensations as something external. In brutes the co-operation of instinct renders this re-action of the sensorium, under the impression of external objects, much less indefinite, for the young animal soon applies itself to the nipple of the mother ; so that its sensorium must be the seat of an innate impulse to attain to the image which it sees, and which is an object or something external to the sentient self, by appropriate movements. Though the new-born infant be at first unable to distinguish between the image of its own body and those of external objects, it will soon remark that certain images in the field of vision are constantly re-appearing, and that these images move when its body is voluntarily moved. These are images of parts of its own body. All the other images in the field of vision either change quite independently of the body of the infant, or the changes which they undergo do not correspond with its voluntary movements. These are images of objects appertaining to the external world, which, now recognised as existing in a space external to the body of the individual, are henceforth continually presenting themselves in this space, which, according to the conception of the mind, is subject to the operations of vision. Of the eye as the organ of vision the new-born infant knows nothing.

We have, in fact, little opportunity of perceiving in the act of vision that the eye is its seat. It is only when the eye is the seat of sensation without any definite external objects being perceived, that it is really recognised to be the seat of these actions ; for instance, when darkness is seen before the closed eyes, or when light shines through the closed eye-lids, so as to excite in the eyes the sensation of light. It is thus by the process which we have described that the newly born human being learns to distinguish between the visible external world and himself, or gains the idea of an exterior visible world.

Images of the individual's own body in the field of vision.—Certain parts of our body nearly constantly occupy a part of the field of vision, and therefore have a share in the ideas which the sensations of vision excite in the mind. When we look with one eye only, one side of the field of vision is occupied by the image of one side of the nose. If we depress the eye-brows, the upper part of the field of vision becomes occupied by them. If the cheek be raised, a part of it is seen at the lower part ; and if the outer portion of the orbicularis palpebrarum muscle be contracted, a shadow thrown by the investments of the eye is seen at the outer part of the field of vision. Images of parts of our body may therefore appear in the entire periphery of the field of vision, and then the images of external objects will lie in the space surrounded by them. If we close one eye, and fix the other upon the point of the nose, the

image of the nose will project from one side into the middle of the field of vision. If we direct both eyes simultaneously towards the nose, the image of the point of that organ will lie in the middle of the lower part of the field of vision; while the images of the sides of the nose will be in part deficient, since, at the part where one eye perceives an indistinct image of the side of the nose, the other will see external objects. If the eye be directed more downwards, not merely the nose, cheeks, and lips, but also the trunk and extremities, will appear at the lower part of the visual field. In every position of the eye, however, some one part of our body is always visible, occupying a determinate place in the periphery of the field of vision either above or below, or at the sides; and the image of some part of our body constitutes a part in most of the sensations of vision, and of the ideas attached to them.

Although the images of our body perceived by the sense of vision are merely images depicted on the retina, and by it communicated to the sensorium, they are confidently interpreted, like the images of external bodies, as real objects. The image of our hand, which we see, is not, in point of fact, our hand, but only its representation in the retina. When we grasp any object, the movement is represented in the retina: we see that we grasp the object, for the image of our hand is seen to grasp the image of the object. We are also made acquainted with the performance of the act by means of another sense, namely, by sense of touch in the hand, and the sense of movement in it. It appears an extraordinary circumstance that, although the perception of any part of our body by the sense of common feeling or touch, and by the sense of vision, takes place in such different localities, the two sensations never interfere with each other; they are brought into harmony and unison through the influence of the mind. That this is the case we can render evident to ourselves by an example in which the difference of locality is still more striking, and where nevertheless the two sensations are by the power of the mind not less closely brought into unison.

If while we look at our image in a mirror we move our hands, we are informed of those movements, as well by the sense of feeling as by the image in the mirror; and, although the seat of impressions on the senses of touch and sight is so different, we derive from them through our mental agency but one harmonious idea.

Inverted images and erect vision.—In accordance with the laws of optics, the images are depicted on the retina in an inverted position as regards the objects themselves; what in the object is above, is in the image represented below, and *vice versâ*; the right side of the object is to the left, and the left side to the right; while the relative position of its different parts remains precisely the same. The question now

arises, whether we really see the images inverted, as they are in the retina; or erect, as in the object itself. Since the image, and the affected parts of the retina, mean the same thing, the question physiologically expressed is this: Are the minute divisions of the retina affected in vision perceived by the sensorium in their natural relation to the object?

The view which I take of the question, and which I proposed in my work on the physiology of vision, is, that even if we do see objects reversed, the only proof we can possibly have of it is that afforded by the study of the laws of optics; and that, if every thing is seen reversed, the relative position of the objects of course remains unchanged. It is the same thing as the daily inversion of objects consequent on the revolution of the entire earth, which we know only by observing the position of the stars; and yet it is certain that, within twenty-four hours, that which was below in relation to the stars, comes to be above. Hence it is, also, that no discordance arises between the sensations of inverted vision and those of touch, which perceives every thing in its erect position; for the images of all objects, even of our own limbs, in the retina, are equally inverted, and therefore maintain the same relative position. Even the image of our hand, while used in touch, is seen inverted. The position in which we see objects, we call therefore the erect position. A mere lateral inversion of our body in a mirror, where the right hand occupies the left of the image, is indeed scarcely remarked; and there is but little discordance between the sensations acquired by touch in regulating our movements by the image in the mirror, and those of sight, as, for example, in tying a knot in the cravat. There is some want of harmony here, on account of the inversion being only lateral, and not complete in all directions.

Volkman agrees with this view of the question. He also argues that no explanation of erect vision is required, as long as all things equally, and not some objects only, appear to the eye inverted. Nothing can be inverted where nothing is erect; for each idea exists only in antithesis to the other.

The hypothesis, that erect vision is the result of our perceiving, not the image on the retina, but the direction of the rays of light which produce it, involves an impossibility, since each point of the image is not formed by rays having one determinate direction, but by an entire cone of rays; and, moreover, vision can consist only in the perception of the state of the retina itself, and not of any thing lying in front of it in the external world. The hypothesis, also, that the retina has an *outward* action, and that objects are seen in the direction of decussating lines, that is to say, in the direction of the perpendicular of each point of the concavity of the retina, (Bartels,) is a perfectly arbitrary assumption; since there is no apparent reason why one direction should have

the preference rather than another, and each ultimate sensitive division of the retina, if it had the power of action beyond itself, would act in as many directions as radii might be drawn from it towards the exterior world.

The inversion of objects being a thing of which we can never become conscious in ourselves, it is not probable that nature has made in the brain, or elsewhere, any provision for the correction of the error, which would never have been known but for the institution of optical inquiries. The decussating course of the optic nerves cannot be adduced as an explanation of erect vision, since the decussation is only partial.*

If it were possible to produce an image of an object upon the retina without the aid of light, for instance by immediate contact, the image would in that case not be inverted; and, if it were possible to see the same object simultaneously by means of luminous rays from without, and by immediate impression upon the retina, the images produced in these two ways would appear to lie on opposite sides. This can in fact be shown experimentally. If, we press upon the retina with the finger through the sclerotica, a spectrum produced by the immediate impression of the finger will be perceived; while at the same time the finger may be seen through the medium of the external light. The two images will appear at opposite sides. If, while the eyes are closed in the dark, we press upon what appears to us to be the upper part of one eye with the finger, which is, therefore, seen above, the spectrum produced by the pressure becomes visible below; if the pressure be made upon the lower part of the retina, the spectrum appears above; if the right side of the retina be the seat of the pressure, the spectrum appears on the left side, and *vice versâ*.

Visual direction.—Before wholly quitting this subject, we must take into consideration what has been called by some writers “the direction of vision,” or “visual direction.” Objects, of which the images fall upon the same parts of the retina, lie in the same visual direction. With respect to the causes which determine the direction of vision, two views may be adopted, though one of these only appears to me to be correct.

1. The direction in which an object is seen depends merely on the part of the retina which receives the image, and on the distance of this part from, and its relation to, the central point of the retina; or, in other words, on the position which the affected part of the retina bears in relation to the entire mosaic-like expanse of the membrane. If, by the action of the mind, the images or affections of the retina are projected into the exterior world, the relation of the images to each other remains

* See the observations of Berthold, (*Über das Aufrecht-erscheinen der Gesichts-objecte*: Gött. 1830,) and of Bartels, (*Beiträge zur Physiologie des Gesichtsinnes*: Berlin, 1834,) on this subject.

the same; and the idea which the sensorium receives from the act of vision may be imagined by supposing the whole visual field of the retina to be projected forwards, its different parts maintaining the same relative position, the part which was above remaining above, that which was below still below. Thus if $d b a c e$ (fig. 96) were the retina, and

Fig. 96.

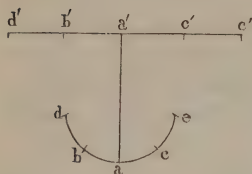
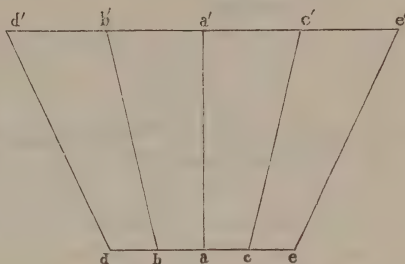


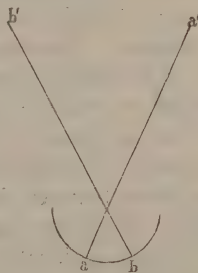
Fig. 97.



the images depicted on it were projected forwards, a' would be the situation towards which a would be projected by the agency of the mind, b' that towards which b would be projected, and so on; the points b' , c' , d' , and e' , of the image conceived by the sensorium lying respectively on the same sides as the corresponding points b , c , d , and e , of the image in the retina: or, if the retina be regarded as a plane surface, the projection of the image would be as in fig. 97. Here the extent ascribed to $d' e'$ would depend on the mind itself; and merely the relative positions of the different points a' , b' , c' , d' , and e' , would remain the same.

2. Opposed to this view is the hypothesis that the images are projected forwards in decussating lines, as in fig. 98; the point a of the image on the retina being, for example, projected forwards towards the opposite side, and seen in the direction $a' a$. Of this hypothesis there are various modifications, dependent on the situation in which the lines of visual direction are supposed to decussate.

Fig. 98.



a. Thus some physiologists suppose that the direction of the light itself is perceived, and that we see consequently in the direction in which the light comes to us; this view, which was shown by Porterfield, and more recently by Volkmann, to be untenable, is, curious to say, adopted in many treatises on physics.

In ordinary vision, every point of the image upon the retina is produced by the apex of a cone or pencil of light, of which the base is the circumference of the pupil. Which, then, of the rays composing this

cone determines the direction of vision? If it be said, the ray occupying the axis of the cone, we may answer that the peripheral rays also are adequate for vision, as in looking through an opening in a card in such a manner that the peripheral rays only enter the eye. If the point a (fig. 99) of any object be at such a distance from the eye that the rays issuing from it meet in a focus in front of the retina at o , and if

Fig. 99.

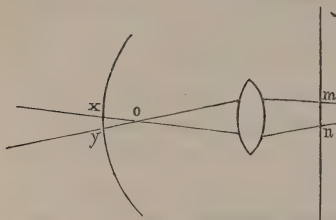
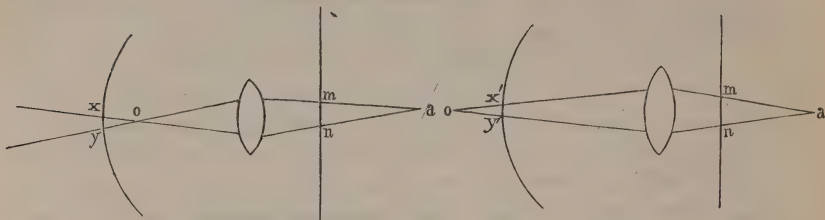


Fig. 100.



m, n , be two perforations in a card, two images of the point a will be formed at x, y , by the peripheral bundles of rays passing through the perforations in the card.

If, on the contrary, the point a be too near the eye, (as in fig. 100,) so that the focus of its cone of light falls behind the retina, and m, n be again openings in a card, two images will still be produced at x', y' , by the bundles of peripheral rays transmitted by the openings in the card. The distance of the point a from the eye may be so regulated, that the images x', y' may be at the same distance apart in the second figure as the images x, y in the first, and the images will then appear in the same position, although the direction of the rays x, o in the first figure, and that of the rays o, x in the second, is so very different.

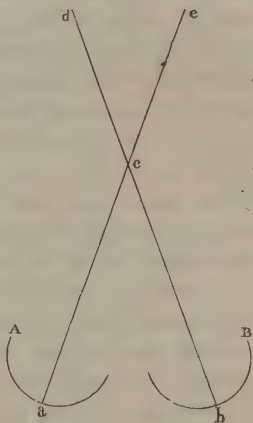
b. The second modification of the hypothesis above mentioned is that proposed by Porterfield and Bartels, namely, that each point of the retina sees the object in the direction of a line perpendicular to itself, or to its tangent. This is an entirely arbitrary assumption.

c. Volkmann proposes a third modification of the same view. According to him, the direction of vision is regulated by the position of the sentient point of the retina in relation to the decussating point of the visual rays; which point is, according to his inquiries, situated in a line drawn between the image on the retina and the object (see page 1132). That the direction of vision is thus regulated, he supposes to be owing to an innate and inexplicable law. It is certain that the most perfect accordance, in a physical point of view, subsists between the objects and their images on the retina, and that lines drawn from the one to the other do all pass through such a point of decussation. Nevertheless, I cannot ascribe to the optic nerves a power of exterior action in a determinate and exclusive direction. Volkmann presupposes the ex-

istence of an inexplicable innate relation between the separate sensitive points of the retina and a point of decussation situated behind the lens. But the former view of the subject does not require the assumption of any such inexplicable condition. The direction in which each image is seen is there supposed to be determined merely by the situation which it occupies upon the retina, and by the relation which this spot bears to the rest of the membrane; and the images to be projected forwards by the action of the mind in the same order as that in which they exist on the retina, but not in decussating lines. The projection of the images towards the exterior cannot be regulated by the mere curve of the retina, but must, in my opinion, be dependent on the arrangement of the elementary parts of that membrane with regard to each other.

All explanations of the direction of vision which are founded on the hypothesis of the projection of the images in decussating lines have one defect in common. The phenomena of vision with two eyes simultaneously are wholly at variance with them. If visual direction be dependent on an exterior action of the retina in any determinate direction, either in the direction of the point on which the eye revolves, or in a direction perpendicular to the retina, single vision with two eyes becomes inconceivable; for, by the eye A (fig. 101), the image of the object *c* falling upon the central point of the retina *a* will be seen in the direction *a c e*; while, by the eye B, the image of the same object, *c*, falling upon the central point of the retina *b*, will be seen in the direction *b c d*. Hence, according to this hypothesis, the image of the same object, *c*, will be seen at two different parts of the field of vision. This objection is not answered by saying that the central points of the two retinæ always see the object singly, or have but one perception from their two impressions; for, if they see the same object in the same spot of the field of vision, they cannot project the images of it in the directions *a c e* and *b c d*. But if the direction in which an object is seen depends simply on the relation which the affected portion of the retina bears to the whole membrane, the image of *c* falling upon the identical points of the two retinæ will be seen single, and will occupy the middle of the common field of vision of the two eyes.

Fig. 101.



Estimation of form, size, distance, and motion.—The estimation of the form of bodies by sight is the result partly of the mere sensation, and partly of the association of ideas. Since the form of the

images perceived by the retina depends wholly on the outline of the part of the retina affected, the sensation alone is adequate to the distinction of mere superficial forms from each other, as of a square from a circle.

Molyneux proposed to Locke the question, whether a person born blind, who was able by the sense of touch to distinguish a cube from a sphere, would on suddenly obtaining his sight be able to distinguish them by the latter sense. It is difficult to conceive wherefore these two philosophers answered the problem in the negative; for the senses of touch and sight are both based on the same fundamental faculty by which we are rendered conscious of the extension of our own organs in space. Hence a new-born animal, when it sees the nipple of its mother, immediately perceives the definite form of that object; and this alone proves that the comprehension of simple forms is not a faculty acquired by education.

The estimation of the different dimensions of bodies from their images on the retina is, on the contrary, a result of experience; since all the ideas obtained by vision refer originally to superficial extent only, and the idea of a solid body, or a body of three dimensions, can only be attained by the action of reason constructing it from the different superficial images seen in different positions of the eye with regard to the object. To the youth restored to sight by Cheselden all objects appeared at first as if painted on one surface, as, in fact, they are; but from the changes which the images on our retina undergo during progression, in which we pass, as it were, between the images, the idea of the depth of the field of vision is originated in our mind; the field of vision is, indeed, merely a conception of the mind, and not a perception of sense.

[From the interesting facts observed by Mr. Wheatstone relative to binocular vision, it appears that our belief in the solidity of a body of three dimensions, such as a cube, arises in a great measure from two different perspective projections of it being presented simultaneously to the sensorium by the two eyes (see page 1205). The influence of this circumstance is greater in proportion as the object is nearer to the eyes, and ceases when it is so distant that the optic axes in regarding it are parallel, the pictures then received by the two retinae being exactly similar. A person who has lost one eye is destitute of this aid in distinguishing the form of near objects, but he supplies the defect by the motion of his head, by which means he causes his single eye to receive different pictures of an object, such as would be received by the two in binocular vision.]

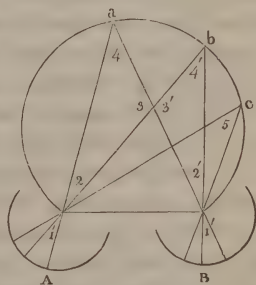
The apparent size of objects depends primarily on the size of the affected parts of the retina, or on the size of the angle under which the objects are viewed by the eye (see page 1131). The idea of the true size of objects from their apparent size is the result of practice, and of the combination of previous ideas of distance, proximity, &c. [Mr. Wheatstone has ascertained that the degree of inclination of the optic

axes with which an object is viewed has a great influence on our idea of its magnitude.] *

The estimation of proximity and distance is not obtained directly from the sensation, but by an action of the reasoning powers. An object is regarded as distant when the visual angle under which its image falls upon the retina is smaller than it is when the object is known to be near the eye. An object appears more distant than others when it is in part concealed by the others, or appears relatively smaller than it should do if it were situated at the same distance as the other objects. This idea of distance is acquired, and in man, at least, is not innate. To the child everything appears equally distant, and it grasps at the moon as at the nearest object.

Most physiologists maintain that the position of the axes of the eyes required for distinct vision of an object also contributes in a great degree to enable us to estimate its distance; the axes of the eyes converging more and more, the nearer the object is to them. The influence of this circumstance is, however, estimated too highly. When the objects lie in a straight direction in front of the eyes, it may certainly have considerable effect; but, when they lie laterally, the position of the axes of the eyes cannot longer be of any assistance in judging of their distance; for distinct vision of objects situated at the sides of the field of vision requires an inclination of the axes of the eyes very different from that necessary for the perception of objects in the middle of the field of vision even when they lie in the same plane. Thus the degree of convergence of the axes of the eyes for the perception of the points, *a*, *b*, and *c* (fig. 102) is the same; and, nevertheless, *a* is very distant from the eyes, the lateral object *c* very near to them. The angles 4, 4', and 5 are equal, if the line *abc* be a circle; for it is the property of a circle that triangles erected towards its periphery, and having a common chord for their base, have equal angles at that periphery. Hence, from the circumstance of objects requiring the same inclination of the axes of the eyes for their distinct perception, we do not learn that they lie at the same distance from the eye, but that they lie in a circle, as the points *a*, *b*, *c*.

Fig. 102.



[The circumstance of objects being viewed from two different points of sight simultaneously by the two eyes, which has been shown by Mr. Wheatstone to afford great aid to the mind in estimating forms, was distinctly pointed out by Le Cat in the following paragraph, as assisting us in judging of the distance of objects, although he attributed more import-

* Mayo's Physiology, 4th Ed. p. 284.

ance to our consciousness of the degree of inclination of the optic axes:—"I do not doubt that the more or less extended succession of different bodies between the objects and ourselves aids this judgment; but the concurrence of the optic axes of the two eyes is itself necessary to enable us to distinguish well this series of interposed bodies: thus, this concurrence of the axes, and the length of the angle they form, are the fundamental principles for estimating the distance of objects: hence it is, that when we look with one eye only, we are unable to distinguish distances, and cannot place the end of the finger directly upon an object indicated to us, though it be very near, for the finger hides the object, and appears to correspond to it as exactly when it is at the distance of a foot as if it were only a line removed from it. But, if our other eye be open, it will see the finger and the object from the side, and will therefore discover a considerable interval between them if they are a foot distant from each other, but only a very small interval if they are very near; and thus we are enabled to place our finger with certainty upon the desired object."*]

We judge of the motion of an object, partly from the motion of its image over the surface of the retina, and partly from the motion of our eyes following it.

If the image upon the retina moves while our eyes and our body are at rest, we conclude that the object is changing its relative position with regard to ourselves. In such a case the movement of the object may be apparent only, as when we are fixed upon a body which is in motion, such as a ship. If, on the other hand, the image does not move with regard to the retina, but remains fixed upon the same spot of that membrane, while our eyes follow the moving body, we judge of the motion of the object by the sensations of the muscles in action to move the eye, or by the currents of nervous energy sent by the sensorium to those muscles. If the image moves over the surface of the retina while the muscles of the eye are acting at the same time in a manner corresponding to this motion, as in reading, we infer that the object is stationary, and we know that we are merely altering the relation of our eyes to the object. Sometimes the object appears to move when both object and eye are fixed. This is the case in the vertigo produced by moving our body round on its axis; surrounding objects then, when our body and eyes cease to move, appear to perform a circular motion in the opposite direction to that in which our head had moved. Some remarkable observations, by Purkinje, seem to show that these apparent motions are owing to an impulse to motion in the determinate direction imparted to the brain; for the direction of the apparent rotation of objects maintained a constant relation to the head, although the position of the head were changed after its own movement was remitted (see page 847). With

these phenomena of apparent motion we must not confound others dependent on spectra left by strong impressions on the retina, of which we shall speak in treating of those spectra. The sensations of rotatory movement of objects, produced by turning the body on its axis, are quite independent of the previous impressions on the retina; for they can be produced by moving round with the eyes closed.

Influence of the "attention" on vision.—Before leaving the subject of the reciprocal actions of the retina and sensorium, we must notice the influence of the mental action upon the act of sensation itself.

The mind can, by the faculty of "attention," concentrate its activity more or less exclusively upon the senses of sight, hearing, and touch alternately. When exclusively occupied with the action of one sense, it is scarcely conscious of the sensations of the others. The mind, when deeply immersed in contemplations of another nature, is indifferent to the actions of the sense of sight, as of every other sense. We often when deep in thought have our eyes open and fixed, but see nothing; which is owing to the action of the fibres of the optic nerves being unable to excite the sensorium to perception while it is acting in another direction: for vision, therefore, "attention" of the mind is necessary. But by this faculty of "attention" we also analyse what the field of vision presents. The mind does not perceive all the objects presented by the field of vision at the same time with equal acuteness, but directs itself first to one and then to another. The sensation becomes more intense according as the particular object is at the time the principal subject of mental contemplation. Any compound mathematical figure produces a different impression, according as the attention is directed exclusively to one or the other part of it. Thus, in figure 103, we may in succession have a vivid perception of the whole, or of distinct parts only; of the six triangles near the outer circle, of the hexagon in the middle, or of the three large triangles. The more numerous and varied the parts of which a figure is composed, the more scope does it afford for the play of the attention. Hence it is that architectural ornaments have an enlivening effect on the sense of vision, since they afford constantly fresh subject for the action of the mind.*

Fig. 103.



2. Of the "ocular spectra" consequent on impressions on the retina.

The duration of the sensations of the retina is much longer than that

* On the influence of attention in the sense of vision, see Purkinje, *Beobachtungen und Versuche zur Physiologie der Sinne*; Prag. 1823, 1: and Tourtual, *loc. cit.* On the subject of the influence of the mind on the sensations of vision generally, see Heermann, *Über die Bildung der Gesichtsvorstellungen aus den Gesichtsempfindungen*; Hannover, 1835.

of the impressions which produce them: according to Plateau,* the sensation persists 0·32 to 0·35 of a second after the impression has ceased; and the duration of the “after-sensation,” or “spectrum,” is greater in a direct ratio with the duration of the impression which caused it. Hence the image of a bright object, as of the panes of a window through which the light is shining, may be perceived in the retina for a considerable period, if we have previously kept our eye fixed on the object for some time. The duration of these images in the closed eyes may also be very much prolonged, by passing the hand up and down before them, so as to permit the light to fall upon them only at intervals. The after-duration of sensations consequent on impressions on the retina explains the appearance of a circle of light produced by moving a luminous body in a circle before the eyes, as well as that of the confusion of the images of the spokes of a rapidly revolving wheel, or of the prismatic colours painted upon a spinning top.

[It has been noticed by several observers, that the ocular spectra frequently disappear, return, and again disappear. This fact, which any person can readily verify, may assist in explaining the following phenomena.]

If we gaze for a considerable time upon a body which presents a continued motion of different parts of its surface in succession, the spectra left on the retina have also an appearance of motion in the same direction, owing to their disappearing from the eye in the same order. This is, in my opinion, the proper mode of explaining certain illusory appearances of motion in objects. If, after looking for a long time at the undulations of a stream of water, we suddenly turn our eyes to the ground at its margin, the ground itself appears to move, in the opposite direction to the waves of the water. I have frequently remarked this phenomenon, when, after gazing from my window upon the neighbouring river, I have directed my eyes to the pavement of the street. I observed it also when, being on board a steam-packet, and, having looked for some length of time upon the waves which passed, I suddenly turned my eyes towards the deck of the vessel. If we suppose that in these cases spectra were left in the retina by the impressions of the waves, and that they disappeared in the order in which they arose, their successive disappearance while looking upon the fixed surface of the ground or deck would necessarily cause an apparent motion of this surface in the opposite direction.

The ocular spectra may be divided into three classes. They are either colourless spectra left by colourless images, or coloured spectra after colourless images, or coloured spectra after coloured images.

* Fechner's *Repert.* 2, 210.

*Colourless spectra left by colourless images of real objects.**—The spectra left by the images of white or luminous objects are ordinarily white or luminous; those left by dark objects are dark. Thus, the spectrum of a luminous body rapidly moved before the eyes is also luminous. If the eye, after being subjected to a vivid impression, be closed and turned away from the light, or, what is better, quite covered, white or luminous spectra of the objects which were white and luminous are seen, and dark or black spectra of those which were dark or black. Thus, if while sitting in our room we look for some time at the light window with its dark framework, and then suddenly close the eyes, turn them from the window and cover them with the hand, so that no light, not even that which would pass through the eye-lids, can reach the eye, bright spectra of the panes of the window, and a dark spectrum of the framework, are seen.

The relation of the light and dark parts in the image may, however, under certain circumstances, be reversed in the spectrum; what was bright may be dark, and what was dark may appear light. This occurs whenever the eye which is the seat of the spectrum of a luminous object is not closed, but fixed upon another bright or white surface, as a white wall or a sheet of white paper. Hence the spectrum of the sun, which, while light is excluded from the eye, is luminous, appears black or grey when the eye is directed upon a white surface. In the same way the spectra of the window-panes appear dark, those of the dark framework light, if we look with closed eyes towards the light of the window, so that the light passing through the eye-lids gently stimulates the retina. These phenomena are easily explained. The part of the retina which has received the luminous image remains for a certain period afterwards in an excited state, while that which has received a dark image is in an unexcited, and therefore much more excitable condition. If the eye in this condition be directed towards a white surface, the luminous rays from this surface produce upon the excited parts of the retina a much more feeble impression than upon the other parts which are as yet unexcited, and therefore more susceptible of their action. Hence the parts of the retina upon which the dark portions of the previous image had fallen receive a much more intense impression from the white surface than those upon which the luminous portions of the image were directed; and hence the inversion of the light and dark parts of the image in the spectrum thus seen.

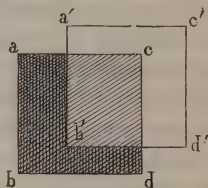
Similar phenomena are presented by the whole field of vision when a sudden change is made from light to darkness, and *vice versâ*. On coming from darkness into a bright light, every object appears exces-

* J. Müller, *Physiologie des Gesichtsinnes*, p. 401.

sively bright, on account of the great susceptibility of the retina after its previous rest; and, on passing from light into moderate darkness, we at first see nothing, until the retina, exhausted by previous excitement, shall have recovered sufficient excitability to be acted on by the slight degree of light to which it is now submitted. A light object always appears brighter when viewed after a dark object, or even when viewed side by side with it. Similar phenomena are observed with relation to the other senses. Cold is felt most intensely when it follows the impression of heat or warmth; and, after exposure to a great heat, a slightly different temperature, which under ordinary circumstances would feel warm, will produce the sensation of cold. The distinctions between light and darkness, heat and cold, are therefore merely relative.

Ocular spectra seem to change their place with relation to our body with every movement of the eyes, and, for an evident reason, are still seen, in whatever direction we may turn the retina. If we look for a long time at a black square upon a white ground, and then divert our eyes slightly, so as not entirely to leave the square, but rather to look more directly at its border, a portion of the spectrum which it has produced, $a' c' d'$ (fig. 104), will appear free upon the white ground, as a bright margin to one part of the dark image a, b, c, d ; while, to a certain extent, the true image and the spectrum will lie upon the same part of the retina, covering each other; another portion of the true image of the object ($a b d$) being left free. In such a case the free portion of the ocular spectrum ($a' c' d'$) appears very bright; the free portion of the true image ($a b d$) very dark; while the parts of the image and the spectrum which are coincident appear of a dark grey colour, as if the two conditions of black and light were there balancing each other. The explanation of the phenomenon is this:—The sensation of white in the part of the retina, $a' c' d'$, which was before the seat of the image of the black object, is more intense, because that part of the retina was previously unexcited; hence the bright margin $a' c' d'$. The part of the image where the true image and spectrum are coincident, remains unchanged. While the portion of the true image which is left free ($a b d$) appears blacker than before, because it now falls upon a part of the retina which had previously received rays from the white ground, and has consequently lost part of its excitability.

Fig. 104.



*Coloured spectra from the impression of colourless objects.**—If the impression of a luminous object on the retina be very intense, as when

* Goethe, Farbenlehre.

produced by the light of the sun's image, the spectrum consequent on it is not merely light when seen upon a dark ground, or dark when the eyes are directed upon a white surface, but assumes different colours in succession, which are expressions of the states which the retina passes through in its transition from the condition of dazzling to its natural state. The dark spectrum of the sun, when the eye is fixed upon a white surface, assumes different colours, from the dark to the light, in the following order:—black, blue, green, yellow, white. The appearance of these colours commences at the borders of the spectrum. When the spectrum has become white, it is no longer distinguishable from the white surface on which it is viewed; that is, the white surface produces now the same sensation in this part of the retina as in all the other parts which had not been submitted to the dazzling action of the sun. If the eye, after viewing the sun, be exposed to perfect darkness, that is, if light be entirely excluded from it, the colours of the spectrum will succeed each other in the inverse order, namely, from white through the lightest, and then the darker colours, to black; thus, in the order of white, yellow, orange, red, violet, blue, and black. When the spectrum has become black, it can no longer be distinguished from the surrounding darkness; the part of the retina which was its seat having regained the same unexcited condition as the other parts which were not acted on by the image of the sun.*

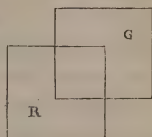
These phenomena, which cannot be explained by any external conditions acting on the eye, are another proof that colours have their immediate cause in the conditions of the retina itself.

Coloured spectra consequent on the impressions of coloured objects.—The ocular spectra which remain after the impression of coloured objects upon the retina are always coloured; and their colour is, not that of the object, or of the image produced directly by the object, but the opposite, or complementary colour. The spectrum of a red object is, therefore, green; that of a green object, red; that of violet, yellow; that of yellow, violet. The spectrum of a blue object is orange; that of an orange-coloured object, blue. The colours which thus reciprocally excite each other in the retina are those placed at opposite points of the circle in fig. 75, page 1103. If we fix our eye for any length of time upon a bright red spot on a white ground, and then suddenly turn it from the red spot and let it rest upon the white surface, we see an ocular spectrum of the red spot, of the same size and form, but of a green colour. If, on the contrary, we turn our eye only slightly to the side, so as to fix it upon the border of the red spot, the spectrum is seen partly covering the object, as in fig. 105. A portion of the true image of the object R appears free, and a portion also of the spectrum distinct from the true

* [Compare Sir D. Brewster's account of his experiments on this subject in his *Treatise on Optics*, p. 307.]

image; but this portion of the spectrum G is green. At the part where the true image of the object still falls upon the same part of the retina that is the seat of the affection producing the phenomenon of the spectrum, the colour of the object is seen, but it is faint and grey, because the retina is there rendered less susceptible of red, by the condition

Fig. 105.



which causes it to have the sensation of green as an ocular spectrum, than at that part (R) of the true image of the object which now lies upon a part of the retina previously directed to the white surface. The mode of explaining these phenomena is twofold; the one theory is based on physical, the other on physiological principles.

1. The explanation on physical principles is this:—White light contains all the colours as its elements. The retina, when long fixed on a red object, is rendered insensible to the red light, but is still susceptible of the impression of the other coloured rays; if it be now directed towards a white surface, being no longer sensible to the red rays contained in the white light, it perceives only the remaining component rays of white light,—those which produce the colours complementary of red, namely, green.

2. The physiological explanation of the phenomenon is as follows:—The perception of any one of the three simple colours consists merely in the retina being in one of those conditions to which it has a tendency when in a state of excitement; if this condition be artificially excited in an intense degree, the retina acquires an extreme tendency to that of the complementary colour, which consequently is perceived as the ocular spectrum.

Either of these explanations is generally adequate to account for the phenomena; and the first, indeed, appears more definite and more probable, but there are facts at variance with it. For if the white light of the surface upon which the eye is directed be the source of the coloured spectrum, the complementary colour ought not to be seen when the eye is turned upon a black surface. But I have shown that the spectrum of any coloured object has the proper complementary colour even when the eye is directed upon a black surface, or into a perfectly dark cavity.*

All persons are not equally susceptible of the phenomena of the coloured spectra. Some individuals perceive them with difficulty, others without any trouble. When once seen, the observation is repeated with extreme ease. Most persons are little acquainted with the ocular spectra, owing to their attention not having been directed to them. When, however, they, and the laws of their production, are known, their

* Müller's Archiv. 1834, p. 144.

constant presence frequently becomes tormenting. Thus, the luminous borders which objects appear to have in twilight are owing to the ocular spectrum appearing at the one or other margin of the image in the retina; and the luminous appearance sometimes observed around objects, as flowers, in the faint light of evening, which by many persons has been regarded as something mysterious, is of the same nature. A devotee before an image may, in accordance with the laws of these phenomena, see a spectrum of the image whichever way he turns his eye.

3. *Of the reciprocal action of different parts of the retina on each other.*

Although each elementary part of the retina represents a distinct portion of the field of vision, yet the different elementary parts, or sensitive points, of that membrane have a certain influence on each other; the particular condition of one influencing that of another, so that the image perceived by one part is modified by the image depicted in the other part. A great number of phenomena, which have hitherto been regarded as different in their nature,—such as the vanishing of objects, the modification of their colour by that of the surface which surrounds them, the appearance of opposite colours under certain circumstances, the coloured shadows and the influence of light upon the sensation of the property of darkness in a neighbouring object, and *vice versâ*,—may be comprehended under one common head, as the result of this relation between the different parts of the retina. Such phenomena may, however, be arranged in two classes; the one including those where the condition existing in the greater extent of the retina is imparted to the remainder of that membrane; the other consisting of those cases in which the condition of the larger portion of the retina excites in the less extensive portion the opposite condition.

A. *Participation of different parts of the retina in each other's condition.* “*Irradiation of sensations.*”—When two opposite impressions occur in contiguous parts of an image on the retina, the one impression is, under certain circumstances, modified by the other. If the impressions occupy each one-half of the image, this does not take place, for in that case their actions are equally balanced. But if one of the impressions occupies only a small part of the retina, and the other the greater part of its surface, the latter may, if long continued, extend its influence over the whole retina, so that the opposite less extensive impression is no longer perceived, and its place becomes occupied by the same sensation as the rest of the field of vision. The lateral parts of the retina, which do not lie in the axis of vision, are more prone to exhibit this phenomenon than the central part; but no portion of the membrane is entirely insusceptible of it. The point of entrance of the optic nerve is the spot where it is most readily produced.

Vanishing of images at parts of the retina not corresponding to the entrance

of the optic nerve.—If we fix the eye for some time, until it is fatigued, upon a strip of coloured paper lying upon a white surface, the image of the coloured object will in a short time disappear, and the white surface will be seen in its place. This experiment succeeds most easily when the image of the coloured paper falls on the lateral parts of the retina; but the central part of that membrane is also capable of presenting the phenomenon. Purkinje [and Dr. Brewster*] have described these phenomena. They prove that the different parts of the retina, after being subjected to long-continued impressions, mutually participate in each other's condition, and that they are, in a limited degree, capable of exciting their own sensations in surrounding parts. Coloured images upon a white ground are best adapted for showing these phenomena; a small black spot upon a white ground disappears with difficulty, and very slowly, on account of the sensation excited by an impression being more vivid when it forms a contrast with surrounding impressions. The disappearance of images from this cause is only of a few seconds' duration; they then reappear.*

Vanishing of images which fall on the point of entrance of the optic nerve.—The disappearance of images at this part of the retina has been long known, having been discovered by Mariotte. If we direct one eye, the other being closed, upon a point at such distance to the side of any object that the image of the latter must fall upon the retina at the point of entrance of the optic nerve, this image is lost either instantaneously or very soon. If, for example, we close the left eye, and direct the axis of the right eye steadily towards the circular spot here represented, while the page is held at the  distance of about five inches from the eye, the cross will vanish, and the colour of the paper will be seen in its place.  The distance of the object from the eye must be about five times as great as its distance from the point on which the eye is fixed. We can satisfy ourselves that this phenomenon arises from the image falling on the point of entrance of the optic nerve, by fixing the same eye upon the cross instead of upon the round dot; the latter object then does not disappear, or only after long persistence of the impression.

* [Journal of Science, vol. iii. p. 289.]

† [May not these phenomena be explained on the supposition that feeble impressions on the retina are inadequate to excite the sensorium to a sustained action? The appearance of the colour of the surrounding surface in the part of the field of vision corresponding to the point of the retina in which, for the moment, no sensation is perceived, may be due to an action of the mind of which we are unconscious. At all events, the analogous phenomenon of the alternate vanishing and reappearance of ocular spectra (see page 1180) can scarcely be attributed to the extension of the state of one part of the retina to another. On the contrary, it would seem more probable that the condition of the retina on which the ocular spectrum depends is persistent, and that the cause of the occasional disappearance of the image has its seat in the sensorium.]

The phenomenon here described has led to the erroneous conclusion that the part of the retina at which the optic nerve enters is insensible to light, while in fact it is sensible, but the impression which it perceives is that which affects directly the rest of the retina, or the more contiguous parts of that membrane. It differs from the rest of the retina only in possessing, in a higher degree, the property of participating in the condition of surrounding parts.*

The facts which we have been considering prove that the elementary parts of the retina are, in a certain measure, capable of a reciprocal action on each other; but the mode of this reciprocal action, or mutual reaction, may be very different from that hitherto described, as we shall now proceed to show.

B. Excitement of opposite conditions in contiguous parts of the retina.—In the phenomena hitherto described, the prevailing condition, or sensation of the retina, extends to parts of that membrane which are differently affected. In the phenomena now to be considered, the affection of one part of the retina influences that of another part not in such a manner as to obliterate it, but so as to cause it to become the contrast or opposite of itself. The former phenomena ensue gradually, and only after the images have been long fixed on the retina; the latter are instantaneous in their production, and are permanent.

Impressions of light and darkness rendered more intense by contrast.—A grey spot upon a white ground appears darker than the same tint of grey would do, if it alone occupied the whole field of vision. Every shadow is rendered deeper when the light which gives rise to it becomes more intense, owing to the greater contrast. The following instance may serve as an example of many such phenomena:—Let the light of a single candle fall upon a sheet of white paper, and the paper will appear white. Now, place a second candle at some distance from the paper, and between them some body, which shall throw a shadow upon the paper; this shadow will appear grey, although the part of the paper on which it falls will still receive the same quantity of light from the first candle as before made it appear white. The cause of the difference is the contrast with the other part of the paper, which now receives light from two candles. For the same reason, a shadow upon a white surface appears much less dark when viewed through a tube, so that

* [Not only will a black spot disappear from a white surface, but a white spot upon a black surface will also become invisible, when it falls upon the base of the optic nerve. In the latter instance, according to the author's theory, the condition of repose of the retina generally extends to the part excited by the rays from the white object, and renders their impression null. This is directly contrary to what occurs in the case of the "radiation" of sensations in the nerves of common sensibility; there, an excited state of one or more nervous fibres extends to others previously in an unexcited condition.]

the surrounding white surface does not produce an impression on the retina at the same time.*

Physiological colours produced by contrast.—A very small dull-grey strip of paper, lying upon an extensive surface of any bright colour, does not appear grey, but has a faint tint of the colour which is the contrast of that of the surrounding surface. Thus, for example:—A strip of grey paper upon a green field often appears to have a tint of red, and when lying upon a red surface, a greenish tint; an orange-coloured tint upon a bright blue surface, and a bluish tint upon an orange-coloured surface; a yellowish colour upon a bright violet, and a violet tint upon a bright yellow surface. For the production of this phenomenon it is necessary that the colour of the extended surface should be very bright, containing abundant rays of white light. Every coloured paper is not adapted for it. It is shown most distinctly by holding a coloured glass covered with thin paper before a lamp, and covering any spot on the glass and paper with a strip of a grey colour. The strip of paper is then readily seen to have the colour which is the contrast to that of the glass. The colours which are thus developed physiologically by contrast, are the complementary colours shown at the opposite points of the circle in fig. 75, at page 1103. The new colour is always that which, combined with the colour of the surrounding surface, would yield the sum of the three simple prismatic colours, red, yellow, and blue. The colour excited by the impression of yellow is, for example, violet, which contains blue and red.

The colour excited thus, as a contrast to the exciting colour, being wholly independent of any rays of the corresponding colour acting from without upon the retina, must arise as an opposite or antagonistic condition of that membrane; and the opposite conditions of which the retina thus becomes the subject would seem to balance each other by their reciprocal reaction. We have also in these phenomena a fresh proof that colours, physiologically considered, are merely certain states of the retina, which are capable of exciting each other reciprocally in different parts of that membrane. A necessary condition for the production of the contrasted colours is, that the part of the retina in which the new colour is to be excited shall be in a state of relative repose; hence the small object itself must be grey. A second condition is, that the colour of the surrounding surface shall be very bright, that is, it shall contain much white light.

Several other phenomena observed by Smith, Sir D. Brewster, and myself, seem to be also of this nature.†

* Tourtual has described many other phenomena of this nature in his tract, *Über die Erscheinung des Schattens*. Berlin, 1830.

† See an account of these phenomena in Müller's *Archiv*, 1834, pp. 144, 145; [and Sir D. Brewster in the *Philos. Mag.* Ser. iii. vol. ii.]

Coloured shadows.—The coloured shadows sometimes observed are phenomena belonging to the same category. But all coloured shadows are not of this nature; some are owing solely to the shadow being illuminated by a coloured light.

a. Coloured shadows dependent on a physical cause.—If a coloured light fall upon a shadow produced by colourless light, or by light of a different colour, the shadow of course appears coloured. In the faint light of evening, the shadows of bodies appear by candle-light blue or yellow, according as the bluish light of the sky or the yellow light of the candle falls upon them. The two kinds of light may produce two shadows of different colours from one body. Of two shadows thus produced by a small rod upon a sheet of white paper, the one which cannot receive any of the bluish light of the sky, but receives light from the candle, will appear yellow; while the other shadow, which receives no light from the candle, but is illuminated by the bluish light of the sky, appears blue. All other parts of the paper present no predominant colour, since they receive rays from both kinds of light. The purely physical nature of these coloured shadows was pointed out by Pohlmann.*

b. Coloured shadows dependent on a physiological cause.—If light transmitted through coloured glass, or reflected from a coloured body fall upon a white surface, and a shadow be produced upon this surface, which now appears coloured, by means of a narrow body raised upon it, this shadow, when illuminated by the white light of day, will appear of the colour which is complementary of that of the surrounding surface. The experiment succeeds also if the shadow be illuminated by the light of a candle. The illumination of the shadow by white light is a necessary condition for the production of the phenomenon. For, as Grotthuss has shown, if coloured light be thrown into a cavity otherwise perfectly dark, a shadow there produced does not appear coloured. Some of the earlier hypotheses offered in explanation of this phenomenon may be wholly passed over. It can only be referred either to a physical action of the coloured and white lights reciprocally on each other, or to the physiological principle of contrast.

Von Münchow has proposed an explanation of the former kind. His view is founded on the assumption, that coloured light has the property of rendering inert those rays of white light, traversing the space occupied by it, which are analogous to its own rays, and of transmitting only the rays of the colour complementary of itself.† According to this hypothesis of Von Münchow, white light traversing a space occupied by blue light would lose the blue rays which it contains, and would be transmitted with merely the remaining complementary orange. To prove that two

* Poggendorf's Ann. 37. 319.

† See Pohlmann, loc. cit. p. 323.

bodies of light, meeting from different directions, may exert an influence on each other, Von Münchow adduces the experiment of Fraunhofer, which showed that one ray of light can divert another from its course. Pohlmann, however, controverts the hypothesis of Von Münchow by the following experiment:—Coloured light was thrown by means of a plate of coloured glass upon a white surface within the cavity of a box, a shadow being produced on the white surface by a strip of some substance placed upon the glass. Instead, however, of illuminating the shadow by allowing the light of day to fall freely upon the white surface, he directed it by means of a tube, the lower end of which passed into the shadow, upon the shaded part only of the surface. But even here coloured light might certainly be reflected from the walls of the box so as to occupy the space of the shadow, and exert the influence which Von Münchow imagines it does, upon the white light.

The coloured shadows are usually ascribed to the physiological influence of contrast; the complementary colour presented by the shadow being regarded as the effect of internal causes acting on that part of the retina, and not of the impression of coloured rays from without. This explanation is the one adopted by Rumford, Goethe, Grotthuss, Brandes, Tourtual, Pohlmann, and most authors who have studied the subject.

An argument in favour of this view is the fact observed by Count Rumford, that the colour of the shadow does not appear different from that of an ordinary colourless shadow, when it is viewed through a tube in such a manner that the coloured ground is not seen at the same time.

Great probability is also conferred on this explanation of the phenomena by their analogy with the facts previously spoken of, those in which a small grey strip upon a surface of a bright colour appears of the opposite complementary colour. In the case of the coloured shadows, the experiment is complicated with many deceptive circumstances; but in that of the experiment just alluded to the phenomenon is reduced to its simplest conditions.

C. *Pleasing effect of the physiological contrasts of colours; physiological basis of the harmony of colours.**—The phenomena described in the foregoing pages prove clearly that the action of one colour upon the retina disturbs the equilibrium of its condition, exciting in it one predominant state; and that a tendency exists in it to the developement of the opposite state complementary of the one thus excited. We cannot, there-

* Goethe, *Farbenlehre*. [See, also, a memoir on colours, and a new chromatic scale, by M. Nobili, translated in Taylor's *Scientific Memoirs*, vol. i. from the *Bibliothèque Univ. des Sciences*, Genev. 1830; vol. ii. p. 337; vol. iii. p. 35.]

fore, be surprised at finding that the combinations of colours producing a pleasing and salutary impression both upon the eye and upon the mind, are those which contain the colours thus opposed to, or complementary of, each other. All complementary colours have an agreeable effect; and all bright colours which are not complementary a disagreeable one, if they predominate. In this sense the complementary colours may also be styled harmonic, and those which are not complementary of each other disharmonic. A combination of complementary colours is an harmonic combination; all other combinations of colours are disharmonic, in proportion as they belong to one simple prismatic colour, and are at the same time very bright. A predominant flaming red is as unpleasant as a predominant glaring yellow, or a uniform predominant blue. Hence we are accustomed to mingle white or grey with these colours, when it is requisite to employ them alone over any extent of surface, so as to soften them and render them more supportable. But the purest red is pleasing when associated with its complementary colour, green; blue when combined with orange or gold; yellow when combined with violet. In figure 75, page 1103, the complementary or harmonic colours are placed at opposite points of the circle, and we see at once what mixture of colours will harmonize with another mixture previously determined. Women of good taste, when they have a single predominant colour in their dress, select a dull one; or, if they wear the pure colours, combine those which harmonize from being complementary of each other; for instance, they wear a red shawl over a green dress; combine lilac with yellow, or blue with orange. How beautiful and pleasing to the eye is the combination of a golden orange colour with blue; for instance, of an orange fringe with blue drapery! while the dress of a female, in which pure yellow were combined with red, or yellow with blue, or blue with red, would by every person be regarded as hideous and out of taste. Such striking combinations of disharmonic colours are chosen only for national signs and for the dress of soldiers.

Combinations of two of the simple colours, the third which would render them complementary being deficient, are the most offensive to the eye; for instance, combinations of yellow and red, blue and red, or yellow or blue. In these combinations there is complete disharmony; while, in the association of two colours of which one forms the transition to the other, there is neither harmony nor disharmony,—such colours are indifferent to each other,—as, yellow to green, red to orange, or violet to blue. The disharmony between two colours may, however, be removed by the interposition of a third colour, which is the harmonic of one of them, and is indifferent with relation to the other. We have examples of this in such combinations as red, green, and yellow; yellow, violet, and red; blue, orange, and red; or red, green, and blue, &c. The

disharmony between red and yellow is removed by the presence between them of green, which is the harmonic of red, and is indifferent with regard to yellow.

Painters either intentionally, or without being aware of it, make constant application of these physiological principles; and the pleasing effect of the colours in a picture depends on the skilful combination of harmonic colours, and the prevention or solution of the disharmonies. The application of this principle is often carried so far as the imitation of the coloured shadows. By employing principally the dull grey colours the danger of disharmonies is avoided, but the whole charm arising from the harmonic combinations of colours is at the same time renounced.*

4. *Of the simultaneous action of the two eyes.*

The simultaneous action of the two eyes in vision gives rise to the phenomena of single vision by the two organs under certain conditions, of double vision under other conditions, and of the contention for predominance between the fields of vision perceived by the two retinæ.

Of single vision with the two eyes.†—The phenomenon of single vision, resulting from the simultaneous action of two organs of vision, has by some physiologists, as M. Gall, been thought to be most easily explained by supposing that we do not really employ both eyes simultaneously in vision, but always see with one only at a time. This especial employment of one eye in vision certainly occurs in persons whose eyes are of very unequal focal distance, but in the majority of individuals both eyes are simultaneously in action in the perception of the same object; of this it is easy to convince oneself by the observation of the double images seen under certain conditions. If two fingers be held up before the eyes, one in front of the other, and vision be directed to the more distant, so that it is seen singly, the nearer will appear double; while, if the nearer one be regarded more particularly, so as to appear single, the more distant will be seen double; and one of the double images in each case will be found to belong to one eye, the other to the other eye.

Single vision results only when certain parts of the two retinæ are affected simultaneously; if different parts of the retinæ receive the image of the object, it is seen double. We have, therefore, first to learn by experiment which are the parts of the retina in the two eyes which correspond to each other in the property of referring the images, which affect them simultaneously, to the same spot in the field of vision.

* This subject has been fully treated of by Runge in his work, *Über die Farben*, from which the materials for the above sketch have been chiefly derived.

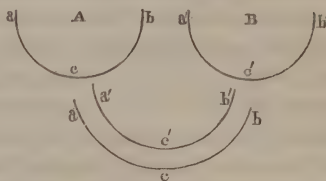
† J. Müller, *Physiologie des Gesichtsinnes*; Leipz. 1826; p. 71.

The knowledge of these parts, which for the sake of brevity may be termed the identical parts of the retina, is obtained in the following manner:—

If while in a dark room, our eyes being closed, we press with the finger upon any part of the ball of the eye, so as to affect the retina, a luminous circle is seen in the field of vision, and, for reasons stated at page 1172, at the opposite side of the field of vision to that on which the pressure is made. If we exert pressure with the finger at the upper part of one eye, and at the lower part of the other eye, two luminous circles are seen, one above the other; the upper circle resulting from the pressure made at the lower part of the one eye, the lower from the pressure made at the upper part of the other eye. These points in the retina of the two eyes are therefore certainly not identical; for affections of them are referred to perfectly different parts of the field of vision.

If pressure be made upon the outer part of both eyes, two figures are again seen, of which the one belonging to each eye is on the opposite side in the field of vision. If pressure be made on the inner side of each eye, two luminous circles are produced, but they lie at the extreme limits of the field of vision; the one on the right side belongs to the right eye, that on the left side to the left eye. It is certain, therefore, that neither the upper part of one retina and the lower part of the other are identical, nor the outer lateral parts of the two retinae, nor their inner lateral portions. But the outer lateral portion of one eye is identical with the inner portion of the other eye; or *a* of the eye A (fig. 106) with *a'* of the eye B. The upper part of one retina is identical with the upper part of the other; and the lower parts of the two eyes are identical with each other. If, for example, pressure be made with the fingers upon both eyes simultaneously at their lower part, while they are closed and no light is shining upon them, one luminous ring is seen at the middle of the upper part of the field of vision; if the pressure be applied to the upper part of both eyes, a single luminous circle is seen in the middle of the field of vision below. So also if we press upon the outer side *a* of the eye A, and upon the inner side *a'* of the eye B, or, what is the same thing, upon the left side of both eyes, a single spectrum is produced, and is apparent at the extreme right of the field of vision. Or if the point *b* of one eye, and the point *b'* of the other, receive the pressure, that is, the right side of both eyes, a single spectrum is again seen, namely, to the extreme left. In short, we may regard the spheres of the two retinae as lying one over the other, as in the

Fig. 106.



lower figure; so that the left portion of one eye lies over the identical left portion of the other eye, the right portion of one eye over the right portion of the other eye with which it is identical; and so with the upper and lower portions of the two eyes, a lies over a' , b over b' , and c over c' .

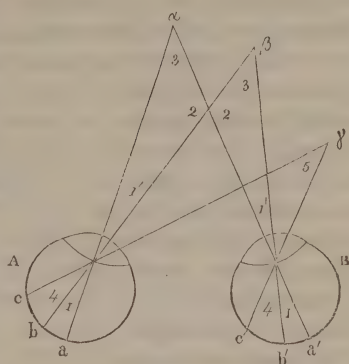
The points of the one retina intermediate between a and c , are again identical with the correspondent points of the other retina between a' and c' ; those between b and c of the one retina, with those between b' and c' of the other. For if pressure commencing at identical points of the two eyes—for instance, on the left side of each,—be carried simultaneously upwards towards the upper part of each eye, the spectrum will remain single, and the pressure may in this way be made to travel in the complete circle in each eye, and still but one spectrum be seen. But, as soon as the finger in either eye is made to press upon a spot not identical with the point compressed in the other, double spectra immediately appear.

This experiment leads at once to the conviction that parts of the retina which correspond exactly in situation, are also completely identical in sensation. Parts of the retina which lie in the same segments of the sphere, in the same meridian and the same parallel of latitude, the middle point of the retina being regarded as the pole,—or which lie at equal distances in the same direction from the centre of the retina,—are completely identical. All other parts of the retina are non-identical; and, when they are excited to action, the effect is the same as if the impressions were made on different parts of the same retina; and the double images belonging to the eyes A and B, are seen at exactly the same distance from each other as exists between the image of the eye A, and the part of the retina of the eye A which corresponds to or is identical with the seat of the second image in the eye B; or, to return to the figure already used in illustration (fig. 106), if a of one eye be affected, and b' of the other, the distance of the two spectra a and b' will, inasmuch as a is identical with a' , and b with b' , lie at exactly the same distance from each other as spectra produced by impressions on the points a , b of the one eye, or a' , b' of the other.

The application of these results to the phenomena of vision produced by external objects is self-evident. If the position of the eyes with regard to a luminous object be such that similar images of the same object fall on identical parts of the two retina, the object cannot be seen otherwise than single; but in any other case two images must be seen. That position of the eyes with regard to an object by which identical parts of the retina receive an image of the object, is attained when the axes of the eyes meet in some one point of the object as always happens when vision is directed particularly to the object.

If the axes of the eyes, A and B (fig. 107), be so directed that they meet at a , an object at a will be seen singly at the same spot in the middle of the field of vision, for the point a of the one retina, and a' of the other, are identical. But other objects, also, which lie to the side of a ,—for example, β and γ ,—may also appear single. If the object β be so situated that its image falls in both eyes at the same distance from the central point of the retina,—namely, at b in the one eye, and at b' in the other,—the image of β affecting identical parts of the retina will be seen single. In the same way, the object γ will be seen single if the distance of the point of the retina c from the point a in the eye A, be the same as that of the point c' from the point a' in the eye B.

Fig. 107.



A straight line, or plane, passing through the point of convergence of the axes of the eyes, or the point towards which the eyes are directed, was called by the older philosophers the "horopter;" and it was imagined that even the lateral objects situated in this horopter were seen single. On closer inquiry, however, it is found, that the horopter can neither be a straight line nor a plane, but must have a circular or spherical form.* The problem to be determined is this:—If the points a , b , c of the one eye be identical with the points a' , b' , c' of the other eye, and, consequently, the angles 1 and 4 of the one eye equal to the angles 1 and 4 of the other eye, can the points a , β , γ lie in a straight line, or in what form of line must they lie?

a , b being equal to a' b' , and the angle 1 in the eye A equal to the angle 1 in the eye B, the angles 1' and 1' will be equal. And since the angles 2 and 2 are equal, the angles 3 and 3 must also be equal. In the same way it may be shown that the angle at γ ,—namely, the angle 5, is equal to the angle 3. For $b c = b' c'$, $\angle 4 = \angle 4$. It being shown that the angles 3, 3, and 5 are equal, it follows that a , β , γ cannot lie in a straight line, for it is the property of a circle exclusively

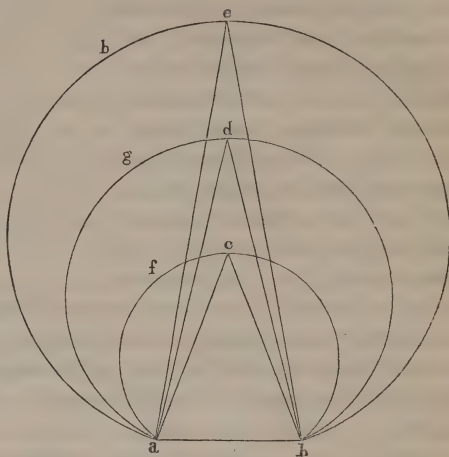
* I demonstrated this in my work, *Über die Physiologie des Gesichtsinnes*. Many physiologists have ascribed to me the discovery of the true form of the horopter, and I also imagined for a long time that I had first taken the above view of the matter; but in *Gehler's Physik. Wörterb.* iv. 2, Leipz. 1828, p. 1472, I see that Vieth had already shown, (*Gilbert's Annalen*, 58, 233,) that the horopter must be a circle.

that triangles erected upon the same chord, and reaching to the periphery, have at the periphery equal angles.

The horopter is therefore always a circle, of which the chord is formed by the distance between the eyes, or, more correctly, between the points of decussation of the

Fig. 108.

rays of light in the eyes, and of which the size is determined by three points,—namely, by the two eyes, and the point towards which their axes converge. If *a*, *b*, fig. 108, be the distance of the eyes from each other, the circle *f* is the horopter for the object *c*, the circle *g* that for the object *d*, and the circle *h* that for the object *e*.



The cause of the impressions on identical points of the two retinæ giving rise to but one sensation, and the perception of a single image, must lie in the organization of the deeper or cerebral portion of the visual apparatus; it must at all events depend on some structural provision; for it is the property of the corresponding nerves of the two sides of the body in no other case to refer their sensations as one to one spot. It is exceedingly improbable that the identical action of the corresponding parts of the two retinæ is the result of a certain habituation, or of the influence of the mind. The co-operation of the two retinæ in one field of vision, whatever is its cause, must rather be the source of all the ideas to which single or double vision may give rise.

It has been urged as an objection to the constant identity in sensation of the corresponding points of the retinæ of the right and left eyes, that double vision sometimes occurs in syncope, intoxication, and nervous affections, where, nevertheless, the harmony of the movement of the eyes, it is asserted, is not lost. (Treviranus.) If double vision necessarily occurs where the axes of the two eyes do not meet in the object, or where this does not lie in the horopter, there are no conditions of which it should be a more natural and inevitable consequence than syncope, intoxication, and nervous febrile affections. The statement of Treviranus, Steinbuch, and of others before them, that the identity of the fields of vision of the two retinæ is acquired, and that though, at the commencement of squinting, objects are seen double, yet afterwards a new relation of identity,

different from the former one, and according with the degree of distortion of the eyes, is established between the two retinae, is also erroneous. Strabismus is a relative term. The position of our eyes required for the convergence of their axes towards a very near object is squinting, as compared with their position in looking at a distant object. In cases where the eyes have an unnatural direction inwards, objects situated in the horopter of this position of the eyes ought to be seen single, and it is not easy to conceive for what distance the new identity of the retinae should be adapted, since the eye which is not affected with the strabismus can accommodate itself to all distances. Moreover, observations made upon persons affected with strabismus do not show that the original relation of the identical parts of the two retinae is disturbed; but that the squinting eye in general does not co-operate in vision.* A presbyopic, or myopic state of the eye, is very often combined with strabismus. The squinting eye, in that case, being adjusted to a very different distance, its field of vision does not at all, or very slightly only, interfere with the impressions of the field of vision of the other eye. Thus even in looking with one eye into the microscope, while the other is directed upon the table at the side, the field of vision of the latter eye, though occupying the same place as that of the other, disturbs but little its perceptions; because the accommodation of the one eye for the perception of the image in the microscope induces a similar adjustment of the other, in consequence of which the table which occupies its field of vision is only indistinctly seen. In a person affected with strabismus, whom I examined recently, I found that under the ordinary conditions for the production of double vision (see page 1201), when one eye is directed so as to have a distinct perception of either of two objects held at different distances from the eyes, no second image of the other object is seen. He distinguishes objects with one eye only, therefore, though both are open.

The accordance of the identical points of the two retinae is, therefore, an innate property, and never undergoes any change. The eyes may be compared to two branches with a single root, of which every minute portion bifurcates so as to send a twig to each eye.

Many attempts have been made to explain this remarkable relation between the eyes.

1. The circumstance of the inner portion of the fibres of the two optic nerves decussating at the commissure, and passing to the eye of the opposite side, while the outer portion of the fibres continue their course to the eye of the same side, so that the left side of both retinae is formed from

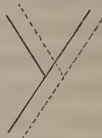
* With reference to the causes of strabismus, see my work, *Physiol. d. Gesichtsinnes*; Priestley, *History of Light and Colours*; and I. N. Fischer, *Theorie des Schielens* veranlasst durch einen Aufsatz des Gr. Buffon. Ingolstadt, 1781.

one root of the nerves, and the right side of both retinæ from the other root, naturally led to an attempt to explain the phenomenon of single vision by this distribution of the fibres of the nerves. Such was the theory of Sir I. Newton* and Dr. Wollaston.† Dr. Wollaston applied this theory to the explanation of the cases which sometimes occur, in which the entire of one side of the retina, as far as the central point in both eyes, becomes insensible; supposing that in such cases the cerebral portion of one optic nerve is paralyzed.‡

2. I have elsewhere shown that this theory is inadequate to explain the phenomenon, unless it be supposed that each fibre in each cerebral portion of the optic nerves divides in the chiasma into two branches for the identical points of the two retinæ, as is shown in the figure (fig. 109).

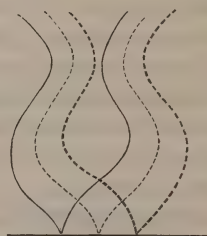
A theory based on the structural relations of the fibres of the nerves might alone be sufficient to explain the phenomena; but such a theory is susceptible of several modifications. The idea of each fibre of the nerves dividing in the chiasma may possibly have occurred to Newton. Treviranus and Volkmann were, however, unable to detect any division of fibres in the chiasma, and I also was unsuccessful in my search for such dividing fibres. Moreover, if this theory were correct, the cerebral portions of the optic nerves ought to have only half the thickness of the ocular portions of the nerves. We must, therefore, remain satisfied with the simple fact, long known, that the cerebral portion of each optic nerve divides at the chiasma into two parts, of which the inner decussates with that of the opposite nerve, while the outer part continues its course to the eye of the same side.§

Fig. 109.



3. A third theory is that of Rohault,|| who, assuming it as a fact that each optic nerve contains exactly the same number of fibres as the other, supposes that the correspondent fibres of the two nerves are united in the sensorium (as in fig. 110). In this theory no account is taken of the partial decussation of the fibres of the nerves in the chiasma.

Fig. 110.



4. A modification, or amendment, of the two preceding theories would be the following, in which regard is paid also to the structure of

* Optics, Quer. 112. † Philos. Trans. 1824. Ann. de Chim. Phys. 1824. Sept.

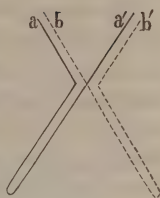
‡ For an account of cases of visus dimidiatus, see Vater, Oculi vitia duo rarissima, visus duplicatus et dimidiatus. Viteb. 1723. 4. recus. in Hall Diss. Med. Pract. t. i. and Ann. de Chim. Phys. 1824. Sept.

§ See the representations of this structure in my work on the sense of vision, already referred to. The partial decussation is most distinct in the horse.

|| Physic. p. i. cap. 31.

the chiasma:—The fibres *a* and *a'*, coming from identical points of the two retinae, are in the chiasma brought into one optic nerve, and in the brain either are united by a loop, or spring from the same point of the sensorium, or the same ganglionic corpuscle in the cerebral substance. The same disposition prevails in the case of the identical fibres *b* and *b'*. According to this theory, the left half of each retina would be represented in the left hemisphere of the brain, and the right half of each retina in the right hemisphere.

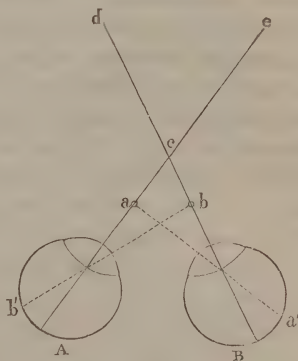
Fig. 111.



5. A fifth theory yet might be adopted; it might, namely, be supposed that a commissural union exists in the middle line in the brain between the identical fibres of the two retinae.

Porterfield* maintains, that the true cause of our not seeing two images of objects viewed with both eyes, is to be found in the faculty we enjoy of seeing the objects in their real situation. But this view is not founded on correct principles, and may be easily refuted. For if the object *c*, which lies in the direction of the axes of the eyes A and B (fig. 112), be seen singly by these eyes

Fig. 112.



merely because they see it in its proper place, the objects *a* and *b* ought to be seen separately by the two eyes for the same reason; but these objects, *a* and *b*, while the position of the axes of the eyes remains as represented in the figure, are not seen separately, but as one in the same spot of the field of vision as *c*, owing to their image falling in both eyes on the same central point of the retina. A double image of *a* is seen, it is true, by the eye B, namely by the point of the retina *a'* and a double image of *b* by the point of the retina *b'* of the eye A; but the images of the points *a* and *b*, which fall upon the centre of the retinae of either eye, are not seen as if in the really separate situations of the objects but as one object, in one spot of the field of vision. We cannot, indeed, correctly say that we see the object *c* single, because we see it where it actually is. The seeing an object in its real place can merely be the seeing it in the direction in which it lies with regard to the eye. The object *c*, however, is seen by the eye A in the direction *c, e*; by the eye B in the direction *c, d*: it

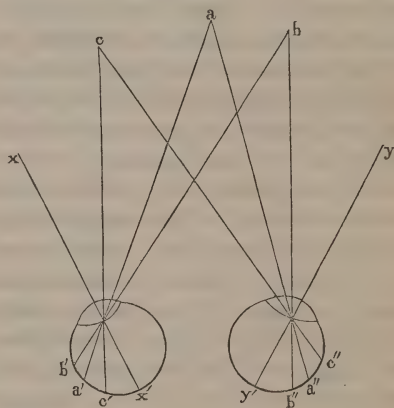
* Op. cit. ii. p. 293.

should, therefore, be seen double according to this theory, while, for reasons already explained, it really appears single.

The cause of the single sensation excited by impressions on identical points of the two retinæ must, therefore, be some organic or structural provision. There are many theories involving the supposition of such a structure, which would account for the phenomena; but not one of these theories can be proved to be the correct one, and, with regard to several of them, it can be shown that they are certainly erroneous. The sort of theory which the facts require is, however, sufficiently evident from the examples given above. [The remarkable phenomena of binocular vision observed by Mr. Wheatstone, (see page 1205,) prove, however, that the impressions on the two retinæ are communicated separately to the sensorium, and are combined to one perception by an action of the mind alone,—not by any organic union of fibres.]

In quadrupeds the relation between the identical and non-identical parts of the retinæ cannot be the same as in man; for the axes of their eyes generally diverge, and can never be made to meet in one point of an object. When an animal regards an object situated directly in front of it, the image of the object must fall in both eyes in the outer portion of the retina. Thus the image of the object *a* (fig. 113) will fall at *a'*

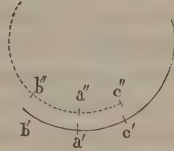
Fig. 113.



in one eye, and at *a''* in the other; and these points, *a'* and *a''*, must be identical; in fact, a dog alters the directions of his eyes according to the distance of the object situated in the direction of his body, just as we do. But the visual axes are not in the dog identical with the axes of the eye-balls; the visual axes in the dog are not the lines *y'y'*, and *x'x'*, but the lines *a'a'*, and *a'a''*. For distinct and single vision of objects, *b* or *c*, lying in front of the animal, and visible to both eyes, it is necessary again that the points *b'* and *b''*, or *c'* and *c''*, in the two retinæ, on which the images of these objects fall, should be identical. All points of the retina in each eye which receive rays of light from lateral objects only, can have no correspondent identical points in the retina of the other eye; for otherwise two objects, one situated to the right and the other to the left, would appear to lie in the same spot of the field of vision. It is probable, therefore, that there are in the eyes of animals parts of the retina

which are identical, and parts which are not identical,—which have no corresponding parts in the other eye. And the relation of the two retinæ to each other in the field of vision may be represented as in fig. 114.

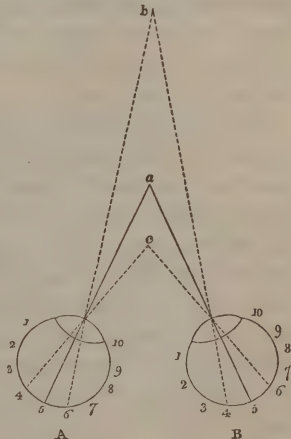
Fig. 114.



*Of double vision.**—Whenever an object lies out of the “horopter” (see page 1195), its image falls on non-identical points of the retinæ, and it is seen double. The double images always lie at a determinate distance from each other; thus, if the image fall in one eye upon the point 6, in the other upon the point 4, the point 6 of the one retina being identical with the point 6 of the other retina, the distance of the two images from each other will be equal to the distance of 4 from 6,—that is to say, the space between the two images, as compared with the extent of the whole field of vision, will be the same as the distance between 4 and 6 in comparison with the diameter of the whole surface of one retina. The simplest experiment for the observation of double images is the following:—Two fingers are held in a straight line before the eyes; one close in front of them, the other at a distance from them. If we look at the first, directing the axes of the eyes towards it, the second is seen double; if we direct our eyes towards the more distant, the nearer finger appears double. The greater the distance between the fingers, the farther do the images of the one seen double appear removed from each other; the nearer the fingers are brought to each other, the more closely do the double images approximate, until at length, when both fingers come within the same horopter, they coalesce.

Fig. 115.

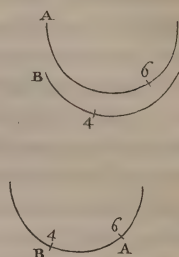
To illustrate this, let *a* (fig. 115) be a point towards which the axes of the eyes are directed, and *b* an object more distant from the eyes. An image of *a* will fall upon identical points of the two retinæ,—namely, upon the central points 5, 5; *a* will consequently be seen single. The image of *b* will fall in the left eye at 6, and in the right eye at 4. The points 4 and 6 of the two eyes being non-identical, since the identical point of one eye corresponding to the point 4 of the other is 4, *b* will be seen double, and the distance between the two images of *b* in proportion to the extent of the whole field of vision will be the same as that between 4 and 6, in comparison with the



* J. Müller, *Physiol. des Gesichtsinnes*, p. 167.

distance between 1 and 10 in each retina. This relation of the double images with regard to each other will be still more evident if the surfaces of the two retinæ be imagined laid one over the other, as in fig. 116, where A is the retina of the left eye, B that of the right eye of the preceding figure; 4 the situation of the image of *b* in the right eye, and 6 that of its image in the left eye. Since the sentient surfaces represented in this figure are essentially identical, the lower figure may be substituted for it; with reference to which it is to be remarked that the image at 6 belongs to the left eye; that at 4 to the right eye.

Fig. 116.



If *c*, in fig. 115, be an object nearer the eyes than the point *a*, towards which their axes are directed, it also is seen double. For an image of *c* will fall in the left eye at 4, in the right eye at 6, points of the retinæ which are not identical; and the distance separating the two images from each other will be the distance 4—5 in the left eye, added to the distance 5—6 in the right eye; or, both eyes being regarded as one, their distance will be that between 4 and 6,—that is to say, the distance between the two images of *c* will bear the same relation to the whole field of vision, as the distance between 4 and 6 to the whole extent of the retina 1—10.

With regard to the position of the double images in relation to the eye to which they respectively belong, it is to be remarked that, when the axes of the eyes decussate at a point nearer than the object, the left-hand image seen in the field of vision belongs to the left eye, and the right-hand image to the right eye. If, on the contrary, the axes of the eyes meet or decussate at a point more distant than the object, the image seen by the right eye lies at the opposite, or left side of the field of vision; that seen by the left eye, at the right side; as is easily ascertained by closing either eye.

This relative position of the images is important in a theoretical point of view. The position of the images in relation to the eyes, which we have just described, appears, at first sight, to be most easily explicable by the theory that we see objects in the direction in which they really lie, and not according to the position of the parts of the retina affected by their images. Thus, when the axes of the eyes decussate at *a* (fig. 115), the more distant object, *b*, is seen double; and the image seen by the left eye should, according to the diagram, appear to the left of the axis of that eye, *a* 5, the image seen by the right eye to the right of the axis *a* 5 of that eye; and so it is found to be by experiment. The phenomena of double vision might, therefore, be adduced as proof of the inverted position of images on the retina being corrected either by the

projection of the images in lines of visible direction, or by a particular course of the fibres of the optic nerves in the brain. The phenomena are, however, explicable by the opposite theory; according to which, the images, or parts of the retina affected by them, are seen in their real position in the retina itself, and are not projected towards the exterior, and seen in the place of the objects.

In the experiment already described, the left of the double images of the object is seen on the left of the middle axis of vision; the object, therefore, according to optical principles, lies to the right. In the perceptions of the retinae no distinction of right and left eye exists; they are identical; but, inasmuch as rays of light are reflected by our own body upon the retina, an image of it is formed there, and, according to optical principles, its different parts are situated on the opposite side to that on which they are seen in the image; the apparent right side of the body therefore is really the left, and the apparent left properly the right. Hence the fact observed in the above experiment, that, when an object is seen double in consequence of the axes of the eyes converging towards a point nearer than it, the left image disappears on the left eye being closed, may also be expressed thus:—If we close the eye of the apparent left, but true right side, the left image of the object disappears; and this is confirmed, indeed, by the construction of the foregoing figures, for the image of *b* lies in the retina of the true right eye B to the left side,—namely, at 4.

The experiments which we have described in illustration of double vision may be varied in many ways; but all the variations are dependent on the same fundamental condition,—namely, that the image of the object falls on non-identical parts of the two retinae.

Thus, if the axes of the eyes are directed, as in figure 117, towards *a*, all other points lying in the line *a, b, c* appear double, because their

Fig. 117.

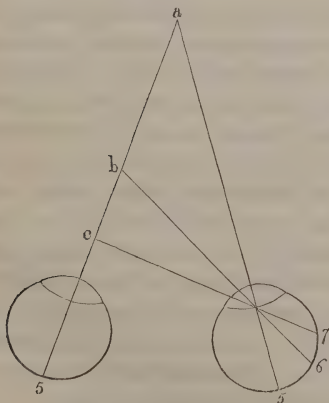
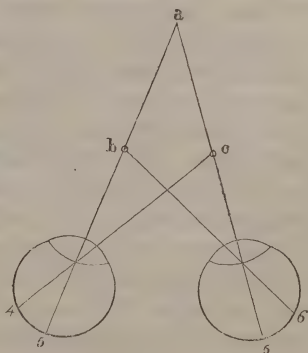


Fig. 118.



images fall in the one eye upon the central point of the retina 5, but in the other eye at different points, 6, 7, 8, 9, &c.

Or again, if, while the eyes are directed, as before, towards *a*, (fig. 118,) two needles are held at the points *b* and *c* in the lines of the axes of the eyes, then in place of two images of *b*, and two images of *c*, or four images, three only will be seen; for the image of the needle *b* will fall in the left eye at 5, that of the needle *c* in the right eye at 5; and, since the points 5 and 5 of the two eyes are identical, these two images will be seen in one point of the field of vision as one. An image of *c* will also fall upon the point 4 of the left retina, and one of the needle *b* at the point 6 of the right retina, which are non-identical points; three needles, consequently, are seen in the order, and at the distance from each other, corresponding with the points 4, 5, and 6 of either retina.

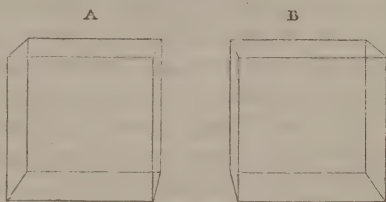
The indistinctness of double images of objects is a necessary consequence of facts with which we have already become acquainted, for they generally fall upon the lateral parts of the retinae; and, even when one lies in the axis of the eye by which it is seen, the proper adjustment of the refractive power of the eye is wanting, since, as we have shown, the adaptation of the refractive power for distinct vision varies in direct accordance with the horopter in which the axes of the eyes decussate.

The phenomena of double vision are so necessary a result of the organization of the eyes, and are so intimately connected with the conditions on which single vision depends, that they must present themselves constantly during the ordinary employment of the eyes. Such, indeed, is the case: but commonly we do not pay attention to them; partly because the images of objects seen double are indistinct, and partly because our eyes are usually directed towards an object in such a way that it is seen single. In all cases, however, where two objects situated at different distances, and not lying in the same horopter, are seen simultaneously, one or other of them must necessarily appear double. Thus, when we look through a window upon a church steeple, either the window-frame or the steeple must appear double, according as the axes of the eyes are directed to the one or the other. Whenever the power of directing the axes of the eyes so as to meet in the object is lost from any cause, double vision must result; hence its occurrence in persons intoxicated, in nervous fevers, in the paroxysms of nervous or hysterical affections, in the state immediately preceding sleep, and in strabismus. This double vision is in no way dependent on any change in the central parts of the nervous system, or in the retina; but is the simple result of the inability to direct both eyes to the object. In the state preceding sleep, and at the moment of falling asleep, our eyes are always rotated strongly inwards; hence at those times all objects—even near objects—appear double. The too great convergence of the eyes can be recognised in the position of the double images; the

left-hand image is found to belong to the left eye. In the state of intoxication, also, the eyes are directed inwards.

[Some important circumstances relative to binocular vision have been pointed out by Professor Wheatstone.* It can scarcely have escaped observation, that, when an object is placed so near the eyes that to view it the optic axes must converge, a different perspective projection of it is seen by each eye, these perspectives being more dissimilar as the convergence of the optic axes becomes greater. Thus, if any figure of three dimensions, an outline cube for

Fig. 119.



example, be held at a moderate distance before the eyes, and viewed with each eye successively, while the head is kept perfectly steady, A (fig. 119) will be the picture presented to the right eye, and B that seen by the left eye. The importance of this circumstance in vision, however, has hitherto been disregarded by all writers on optics. Mr. Wheatstone has shown that on it depends in a great measure our conviction of the solidity of an object, or of its projection in relief. If different perspective drawings of a solid body, one representing the image seen by the right eye, the other that seen by the left, (for example the drawings of a cube A, B, fig. 119,) be presented to corresponding parts of the two retinae, the mind will perceive not merely a single representation of the object, but a body projecting in relief, the exact counterpart of that from which the drawings were made. The two pictures may be made to fall on corresponding parts of the retinae, by placing them one in the direction of each optic axis, at equal distances before or behind their intersection, (for example, at *d*, *e*, fig. 112; or *b*, *c*, fig. 118.) But a better method is, to employ the stereoscope, an instrument invented for the purpose by Mr. Wheatstone, the essential parts of which are two plane mirrors inclined with their backs towards each other, at an angle of 90° . The two pictures, A and B, are placed in the same horizontal line, and parallel to each other, at the sides of these mirrors, and at equal distances from them. The observer then, placing his eyes as near as possible to the two mirrors, their angle coinciding with the middle line of his forehead and face, sees the solid body, represented by the perspective drawings, standing forward in relief, provided the two drawings are so situated that their images reflected by the mirrors coincide with the lines of the convergent optic axes. As the drawings are reversed by reflection in the mirrors, the perspective of the object as seen by the right eye must be presented to the left-hand mirror, and *vice versa*.

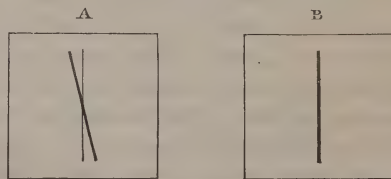
* Philos. Transactions, 1838, pt. ii. p. 371.

Mr. Wheatstone shows also by means of the stereoscope that similar images, differing to a certain extent in magnitude, when presented to the corresponding parts of the two retinae, give rise to the perception of a single object, intermediate in size between the two monocular pictures. Were it not for this, objects would appear single only when the optic axes converge directly forwards, that is to say, when the object is equally distant from the two eyes; for it is only then that the images on the retinae can be of equal size; the size of the image being dependent on the angle under which the object is seen, and this being less as the object is more distant. Thus, if a piece of money be held to the right side of the field of vision, and the optic axes made to converge to a somewhat nearer point, it will appear double, and the image seen by the left eye will be evidently smaller than that seen by the right.

If pictures of dissimilar objects are presented to the eyes simultaneously, phenomena are observed analogous to those perceived when different colours fall upon corresponding parts of the two retinae; the two images do not coalesce, nor do they appear permanently superposed on each other, but at one time one image, at another time the other, will be seen, and, at the moment of change, fragments of the two intermingled will be visible. It does not appear to be in the power of the will, Mr. Wheatstone observes, to determine the appearance of either; but, if one picture be more illuminated than the other, that which is less so will appear during a shorter time.

The fact that two different perspective projections of an object, when they harmonize in suggesting to the mind the same idea, coalesce into one image, is sufficient proof of the incorrectness of the hypothesis that objects can be seen single only when their images fall on identical points of the two retinae.* The following experiment, aduced by Mr. Wheatstone, shows that, under some conditions, similar pictures falling on corresponding points of the retinae may appear double, and in different places; and, consequently, that there is no necessary physiological connection between the corresponding points of the two retinae: — If to one eye we present in the stereoscope a vertical line B, (fig. 119,) to the other eye a line inclined some degrees from the perpen-

Fig. 120.



* [But though it is not necessary that *exactly identical points* of the retinae should be affected by *similar points* of the two images, yet the object will not in general be seen single, unless its images fall on *corresponding parts* of the retinae, as is proved by the experiment of displacing the axis of one eye by pressing on it with the finger, when objects are seen double.]

dicular, we shall see a line, the extremities of which appear at different distances before the eyes. If now we draw a faint vertical line, intersecting the inclined line at its centre, as at A, and present the two drawings to the eyes as before, the two strong lines will still coincide, and the resultant perspective line will occupy the same place; while the faint line, though it occupies the same part of the retina as the vertical line B, appears in a different place, namely, at the intersection of the planes of visual direction of the two eyes. Here it is evidently an action of the mind, employing the impressions on the retinae merely as suggestions for its judgment, which determines the image perceived, and the idea conceived. The influence of the mind on the perceptions of vision is evident even when one eye only is used. Thus, if we look with a single eye at the drawing of a solid geometrical figure, (as the cube A or B, fig. 119,) it may be imagined to be the representation of either of two dissimilar solid figures, the figure intended to be represented, or its converse figure, (which, in the case of the cube, is the frustum of a pyramid with its base remote from the eye). If the former is a very usual, and the latter a very unusual figure, the imagination will fix on the original without wandering to the converse figure: but if both are of ordinary occurrence, which is generally the case with regard to simple forms, the original figure will be perceived distinctly at one time, and at another time the converse; and, while one continues, it is not in the power of the will to change it immediately. The apparent conversion of a cameo, or bas-relief, such as that of a piece of money, into an intaglio, and of an intaglio into a cameo, when viewed with a single eye, especially through a microscope, is a well-known instance of this indetermination of judgment, and is an illustration of the aid we derive in estimating the forms of solid objects from a different projection of them being presented to the two eyes.*]

* [The assertion of Gassendus, Haller, Gall, and others, that we see with only one eye at a time, though both remain open, is refuted, as Mr. Wheatstone observes, by the fact that in many cases (those where the optic axes converge to view a solid object) the simultaneous affection of the two retinae excites a different idea in the mind to that consequent on either of the single impressions; the latter giving rise to the idea of a representation on a plane surface, the former to that of an object in relief; these things could not occur did we see with only one eye at a time. The above assertion, however, though itself incorrect, is founded on correct observations. In many persons one eye is, as Le Cat expresses it, "stronger or more vigilant than the other, and takes upon itself the larger share of the common task." With such persons M. Gall's experiment succeeds perfectly. A narrow body, such as a pencil or pen, held so as partially to obscure a candle, while both eyes are open, will still appear to have the same position when the weaker eye is shut, but will seem to lie much to one side when the eye most used in vision is closed, and the weaker opened. In those persons, on the contrary, whose eyes are equally employed in vision, the position which the body in this experiment holds, when both eyes are open, is intermediate between those which it appears to have when viewed with the respective eyes singly.

With the double vision with two eyes, we must not confound the phenomenon of double or manifold vision with one eye. Most persons, looking at the moon even with one eye, see several images of it, which lie in part one over the other; each, however, having its distinct outline. Like many other persons, I perceive this phenomenon only in looking at such very distant objects. In other individuals, however, it attends the vision likewise of nearer objects.* The cause of this kind of double or manifold vision lies in the physical structure of the eye; it is probably connected with the arrangement of the fibres of the laminae of the crystalline lens into different compartments.

Alternate predominance of the sensations of the two retinae.—One of the most interesting facts relating to the phenomenon of vision is, that the impression of different colours on corresponding "identical" spots of the two retinae does not give rise to one mixed sensation, but that one of the colours predominates in part or in the whole extent of the field of vision, and that the impression made on the other retina is perceived only in spots where the first is wanting. A convenient mode of observing this phenomenon is to look upon a piece of white paper through two differently coloured glasses held close to the eyes; for instance, through a blue and a yellow glass.† The paper, under these circumstances, is not seen of a green colour, but appears in part blue and in part yellow. Sometimes the blue colour predominates, sometimes the yellow; sometimes a blue cloud or spot is seen upon a yellow ground, sometimes the reverse. At one time the blue obliterates the yellow; at another, the yellow the blue. This physiological difficulty was observed by me in another experiment, namely, in distorting the axes of the eyes so as to cause the double images of two objects of different colours to fall upon identical parts of the retina, and therefore to appear to lie one over the other; the two colours, I perceived, did not easily

The part which eyes unequal in power respectively play in vision may be determined more accurately by means of Mr. Wheatstone's stereoscope. In the case of the translator, it is the right eye which determines the position of objects in the field of vision; and the vision of this eye is more perfect, as tested by minute objects held at various distances. When two dissimilar outline perspectives of a solid body, as the cube (fig. 119) are presented to the eyes by means of the stereoscope, the body represented by them is seen standing forwards in relief; but, on closing each eye alternately, it is found that the position of the body, and of its bounding lines, corresponds exactly with the perspective projection presented to the right eye, and differs consequently very much from that viewed by the left eye. Here then the attention of the mind seems to be directed principally to the impression on the retina of the right eye, but yet takes cognizance of the impression on the left retina sufficiently to give rise to the idea and mental perception of a solid body, which would not be acquired without it.]

* See Steifensand in Graefe und Walther's Journ. 1835.—Müller's Arch. 1836, p. CXLVIII.

† For a further account of these experiments see my work *Über den Gesichtssinn*, p. 79. Compare Müller's Archiv. 1836, p. CXLIV; and Volkmann and Heermann, loc. cit.

mingle to form an intermediate tint, as Huschke states, though I admitted the possibility of this occurring. The observations of Heermann and Volkmann agree with mine.

Völckers* has found that if the experiment with glasses of different colours, described above, be long continued, the mingling of the colours, to which there was at first no tendency, becomes more evident; but still, from time to time, one obtaining the predominance appears for a moment alone, or in isolated spots. The mingling of the colours in these experiments has no further physiological interest; but the antagonism of the retinæ, and the yielding of one colour to another in a part or in the whole extent of the field of vision, is of the greatest interest, illustrating as it does most distinctly, in a phenomenon which can easily be observed, the nature of the simultaneous action of the two eyes. For, that their action is the same in regard to other impressions besides colours, may be concluded from the above experiments, and is proved also by other facts.

The appearance at one time of one colour in spots upon the ground of the other; the complete disappearance at another time of one colour, simultaneously with its replacement by the other colour; and, lastly, the union of the two colours to form an intermediate tint, though this is observed only occasionally, prove — 1, that at certain moments the two eyes are both in action together; hence the appearance of spots or nebulæ of one colour upon the ground of the other; 2, that at other moments the impression on one retina is entirely, or nearly entirely, obliterated, and that of the other left predominant; and, 3, that at other periods again the impressions on the two eyes combine to produce one sensation. These states, alternating constantly with each other, present the actions of the eyes to us as phenomena of disturbed equilibrium, like the oscillation of a balance. The state of repose or balance of the impressions is attained with difficulty, though it is possible. The equilibrium is disturbed, however, in part by internal influences unknown to us, and in part probably by the mind being directed more especially to the one or the other eye. The phenomena showing this antagonism of the retinæ are, we may mention, quite distinct and vivid in persons whose eyes are perfectly equal in power, as in myself. The appearance of one colour in spots, or as nebulæ, while all around the other colour prevails, shows moreover the possibility of the different parts of the retina acting unequally; and the phenomenon is, indeed, of the greatest importance, as affording information with respect to the internal conditions of the retina.

The disturbance of the equilibrium between the sensations of the retinæ when both are acting simultaneously is frequently observed

* Müller's Archiv. 1838, p. 60.

under other circumstances. Sometimes, when the axes of the eyes are so directed as to produce double vision, one of the double images of an object suddenly disappears. If the two eyes are adapted for distinct vision at different distances, the image of each alternately prevails and completely supplants that of the other eye. The image of that eye is seen of which the adjustment corresponds to the distance of the object, and to which, consequently, the "attention" of the mind is directed. Sometimes the indistinct image of the other eye floats near the image of the eye which sees distinctly; but often it is not at all perceived, the "attention" not being directed to it. Thus it is also in strabismus, the faulty eye and the sound eye are generally adapted for vision at very different distances; the image received by the former is, therefore, indistinct when that of the other eye is clearly defined, and hence the mind is not directed to it. The total disappearance of the indistinct image under these circumstances is rendered intelligible by the phenomena which we have become acquainted with in the experiments with coloured glasses. Strabismus, indeed, often arises from the indistinctness of the image in one eye; for the eye thus useless in vision ceases to be properly directed towards the object which it is desired to view distinctly, and at last is wholly unemployed.

That the action of the sensorium can be confined to the sensations of one retina, may be observed also in viewing objects through magnifying glasses; for frequently the eye which is looking into the microscope alone sees or distinguishes its object, while the other eye either distinguishes no objects at all, or at least does not see any in that part of the field of vision occupied by the microscopic images perceived by the first eye. Sometimes, on the other hand, the eye not engaged in the microscopic observation resumes its activity, and the image it perceives then seems to float over the image in the microscope and disturbs the observation.

5. *Of the "subjective" phenomena of vision.**

If we exclude from consideration those phenomena affording evidence of action of the retina, which are in some way dependent on the influence of the external light, such as the "ocular spectra," and the phenomena of double vision and the radiation of sensation in the retina, there still remain many others which are dependent on causes of a very different nature. The most remarkable of these phenomena, for a knowledge of which we are principally indebted to Purkinje, are the following:—

Appearances produced by pressure on the retina.—The luminous appearances produced by pressing with the fingers upon the eye (named by

* Purkinje, *Beobachtungen und Versuche zur Physiologie der Sinne*; i. Prag, 1823; ii. Berlin, 1825.

Purkinje "Druckfiguren") vary in form; they are sometimes annular, sometimes star-like, and sometimes regularly divided into squares; whence Purkinje compared them to the figures produced by sonorous vibrations. When a plate of glass covered with water is struck with the bow of a violin, the plate not only divides into vibrating segments, and parts which remain at rest, but the water upon the vibrating parts of the glass presents a most regular distribution into rhombic figures or stationary waves. The figure in the eye calls to mind the appearance of decussating waves.

The vascular figure, described at page 1163, is sometimes seen with a luminous character.—It was sometimes seen thus by Purkinje as the effect of pressure, particularly in the morning; and I have frequently seen this luminous ramified figure in the dark field of vision, when, after ascending a flight of stairs, I have found myself suddenly in a dark place, and also when I have suddenly immersed my head in bathing. The luminous appearance is evidently the effect of the pressure of vessels filled with blood upon the retina.

Luminous appearance produced by the arterial pulse.—When the head is congested with blood, it is easy to perceive that each beat of the pulse is attended by a change in the degree of light perceived by the eyes, by a pulsating illumination of the field of vision. This phenomenon is very easy to observe. Some few times I have seen a similar change in the field of vision, or a rhythmic appearance of a small bright spot, in the middle of the dark field of vision, isochronous with the respiration and the corresponding movement of the brain; but this phenomenon cannot be excited at will, and has presented itself to me only a few times.

Visible movement of the blood.—There are many circumstances under which a general expression of the circulation is perceptible. It is seen, however, more particularly in looking at surfaces which are brightly illuminated, but not to a dazzling degree, as the sky; or after fixing the eyes for some time upon a surface of snow or white paper. The appearance consists in an indistinct confused movement, as of points crossing each other in all directions, or like the motion of vapours. The appearance is so undefined, that the direction of the movement cannot be determined. It evidently is due to the motion of the blood. Of the same nature is the much more definite appearance of dark bodies with tails, flying and moving about in all directions, which is seen sometimes by persons suffering under plethora, or congestion of blood in the head, on rising suddenly from the stooping posture. The sensation of ants creeping over the surface is an analogous affection of the nerves of common sensation or touch.

Luminous circles seen in the dark field of vision on a sudden lateral movement of the eyes.—This appearance is a constant result of suddenly

turning the eyes to either side when in the dark. Two circles of light are always seen; they must therefore be produced by an affection of the retinæ at two different "non-identical" points,—perhaps, at the situation of the entrance of the optic nerve into each eye.

Appearances produced in the eye by electricity.—These phenomena have been investigated by Ritter, Purkinje, and Hjort. If the eye be made to form part of a galvanic circle,—one pole, for example, being applied to the conjunctiva of each eye-lid,—an appearance like a flash of lightning will be perceived when the circle is either closed or interrupted. The same thing takes place also when, although the eye does not lie in the direct line of the electric current from pole to pole, the electricity is nevertheless in part directed towards the eye; as when one pole of the battery is, for instance, applied to the lower eye-lid, and the other to the mucous membrane of the mouth. Even a simple pair of plates of zinc and copper are sufficient to produce the appearance above mentioned in a dark room. A small battery excites more remarkable phenomena: according to Purkinje's experiments, a yellowish light is seen at the zinc pole, a violet light at the copper pole. Under certain conditions, which Purkinje details, peculiar appearances are produced at determinate points of the field of vision, corresponding to the situation of the optic nerve, and to the central point of the retina.

Spontaneous appearances of light in the darkened eyes.—If we direct our attention to what takes place in the eyes when closed, not merely do we see sometimes a certain degree of illumination of the field of vision, but also occasionally an appearance of light developed in greater intensity; sometimes, indeed, this luminous appearance spreads from the centre to the circumference, in the form of circular waves, disappearing at the periphery. At other times the appearance has more the form of luminous clouds, nebulae, or spots; and, on rare occasions, it has been repeated in me with a regular rhythm. Closely connected with these more indefinite appearances in the eye are the more distinct forms seen at the time of falling asleep, or in the period that precedes this, which are due to the action of the mind isolating different definite forms in succession from the cloud-like appearances in the eye, "the chaos of dreams," according to Gruithuisen.

Opposed to these phenomena is the transitory loss of sight, accompanied by the appearances of a mist, coloured smoke, or similar phenomena, before the eyes, which sometimes occurs in persons with a weak nervous system, and which is a state of temporary exhaustion of the retina. A person in perfect health may indeed induce this phenomenon, by looking for a very long time at a white or coloured surface.

Flickering before the eyes after taking narcotic substances.—Digitalis is

most prone to produce this symptom. Purkinje has instituted observations upon it in his own person. If the action of the narcotic is strong, definite forms appear.

Apparent movement of objects consequent on repeated rotation of the body.—This phenomenon has been already described at pages 847 and 848. It must be distinguished with respect to its cause from the apparent movements seen after looking at objects really moving; which arise from the successive disappearance of the spectra left by the moving bodies (see page 1178). The apparent motion produced by the former cause occurs even though the eyes were closed during the rotation of the body.

Defect of the sense of colours.—Owing to an original disposition of the retina, many individuals have in an imperfect degree only the power of distinguishing colours. From numerous observations made on such persons, the younger Seebeck* has obtained the following results:—Besides those persons who find difficulty in determining the colours of objects generally, without however mistaking one colour for another, there are many individuals who are in a more or less complete degree incapable of distinguishing perfectly dissimilar colours from each other. But these persons differ, again, not only in the degree of their defect, but also in its character. Hence Seebeck has divided them, smaller differences being disregarded, into two classes. To the first class belong those who, though differing considerably in the degree of their imperfection of vision, agree pretty nearly in the circumstance of confounding the following colours:—

1. Light orange and pure yellow.
2. Intense orange, light yellowish green, or brownish green, and yellow-brown.
3. Pure light green, grey-brown, and flesh-colour.
4. Rose-red, green (rather blue than yellow), and grey.
5. Crimson, dark green, and hair-brown.
6. Bluish green and imperfect violet.
7. Lilac and bluish grey.
8. Sky-blue, grey-blue, and grey-lilac.

The individuals of this class have a very imperfect power of distinguishing the impression of colours generally; but the defect is greatest with regard to red, and the complementary colour green; these colours being to them scarcely or not at all distinguishable from grey: the colour of which the perception is next in degree defective is blue, which is imperfectly distinguished from grey. The perception of yellow is the most perfect, though objects of this colour also are distinguished from a colourless surface much less easily than by the eye in its normal state.

* Poggendorf's Annal. 42.

Individuals belonging to the second class likewise recognise yellow best; red is distinguished better, blue less perfectly, from the absence of colour, than in persons of the first class: but the distinction of red from blue is above all more imperfect here. The colours which they confound are as follows:—

1. Light orange, greenish yellow, brownish yellow, and pure yellow.
2. Bright orange, yellow-brown, and grass-green.
3. Brick-red, rust-brown, and dark olive-green.
4. Cinnabar-red and dark brown.
5. Dark carmine and blackish blue-green.
6. Flesh-red, grey-brown, and bluish green.
7. Dull bluish green and (somewhat brownish) grey.
8. Imperfect (somewhat yellowish) rose-red and pure grey.
9. Rose-red, lilac, sky-blue, and grey (inclining to lilac).
10. Crimson and violet.
11. Dark violet and dark blue.

It is the perception of the least refrangible rays only that is here very imperfect, which is not the case in persons of the first class.

We must distinguish from the subjective phenomena of vision the images of objects existing in the interior of the eye, and throwing a shadow upon the retina. Such are the thread-like convoluted figures in which rows of globules appear to be contained. These figures are not fixed; not only do the separate parts of the figures alter their relative position, but the whole figures change their place in the field of vision. By an energetic movement of the eyes we can cause them to shift their place somewhat to the side or upwards, but they soon return to their original situation, and after having previously risen, they gradually sink again. Many persons have such figures in considerable number before their eyes, but those in the middle of the field of vision only are seen distinctly. In microscopic observations they often lie in front of the object, and interfere with the perception of it; in such a case I am in the habit of displacing them, by pressing on the eye at the side. In many individuals these appearances are not seen, while to others they are very troublesome. They are by some writers called *muscæ volitantes*, and confounded with certain symptoms which accompany the developement of amaurosis; but they are quite innocent in their nature, and exist in persons whose powers of vision are most acute. I have been subject to them from childhood. Whether they be owing to particles floating in the aqueous humour, or contained in the vitreous body, is not known.

SECTION II.

Of Hearing.

CHAPTER I.

OF THE PHYSICAL CONDITIONS ESSENTIAL TO HEARING.

A MECHANICAL impulse upon the organ of hearing excites in the auditory nerve the sensation of noise, or sound; and, if the impulse be rapidly repeated at regular intervals, a musical tone is heard, the acuteness of which is proportionate to the number of the impulses imparted to the nerve within a given time. Musical tones are most frequently produced by the vibrations of elastic bodies. The sounds produced by the separate impulses of the teeth of a saw, or of the wheel in Savart's experiments, or by the impulses of the water in the siren of Cagniard La Tour (see page 973), give rise, by their quick succession, to a continuous tone. From a vibrating elastic body which makes one thousand vibrations in a second, if we reckon the movement towards both sides, the organ of hearing receives five hundred impulses in a second, propagated to it by the air or other soniferous medium. The effect of these vibrations is the same as that of five hundred direct impulses of a body which does not produce sound by vibrations.

Whether the tones be excited by vibrations or mere impulses, the propagation both of the impulses and vibrations to the organ of hearing is effected in accordance with the general laws of undulatory or vibratory motion. The original production of the sounds which are due to vibrations is also regulated by the same laws, a knowledge of which is consequently necessary in studying the physiology of hearing.

I. *Of undulations in general.**

When the state of equilibrium of the different parts of any body has been disturbed by an external cause, the complete recovery of the previous state of repose is preceded by a movement in which the different parts of the body alternately approach the position of rest, and are removed from it. If a pendulum is driven towards one side, it continues to move in that direction until the moving force = 0; it is then drawn down by the force of gravity, falling with increasing rapidity, which prevents it from immediately resuming the state of rest, and causes it to ascend on the opposite side; and these movements are repeated until the equilibrium is restored. Movements, in which the parts of a body alternately approach and depart from the state of equilibrium, are called vibrations, oscillations, or undulations. *Undulations* are either undulations of

* E. H. and W. Weber, *Wellenlehre*; Leipz. 1825. — Eisenlohr, *Lehrbuch der Physik*; Mannheim, 1836. 121.

inflexion, or flexion-waves, consisting in the surface of the body being thrown into alternate elevations and depressions without any change in its density ; or they consist in successive condensations and rarefactions, without the form of the surface being changed. The rarefactions in this case correspond to the depressions of the undulations of inflexion. Vibrations or oscillations are either progressive, when they traverse the different parts of a body in succession ; or they are stationary, in which case, like those of a pendulum, they do not change their place.

A. *Undulations of inflexion, or elevation and depression, in incompressible fluids.*—The undulations of inelastic fluids are disturbances of the equilibrium of their surface to a certain depth. Gravity is the prime cause of this kind of undulatory movement. Such undulations in water are much too slow to give rise to sound. It is, however, important to become acquainted with their laws, since the laws of undulations generally can be most easily observed in them.

Progressive undulations.—If the equilibrium of a fluid is disturbed at any one point, circular undulations with circular elevations and depressions are formed around this point ; each undulation extending outwards from it, and being followed by another. The stronger the impulse, the higher are the elevations of the waves, and the more rapid is their motion ; though this is also influenced by the depth of the fluid. If undulations are excited in a fluid contained in a deep channel with parallel sides by an impulse acting on the whole breadth of the fluid, their motion is progressive in a straight line, and they do not form circles moving from a centre. The motion of waves is not produced by the progressive motion of the particles of water ; on the contrary, the water itself is stationary, the waves only move over its surface. The particles of water in the situation of a wave merely suffer a movement of rotation : being in a hollow as the wave approaches them, they successively form the most elevated part of it ; the wave still moving onwards, they come gradually to form the depression behind the wave, whence they again rise as the next approaches.

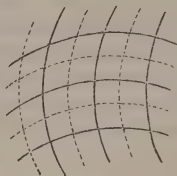
If two waves of equal height meet from opposite points, they intersect each other without the progress of either being disturbed. The elevation of the one, and that of the other, coincide, and form an elevation of double the height of either alone, and the depression of the one also coincides with that of the other. The particles of the fluid here receive impulses to rotation from two forces acting in opposite directions ; and, in consequence of these impulses to rotation neutralizing each other, the particles of water are moved in the vertical direction only. After decussating with each other, the waves move on, each in its own direction.

If, when undulations meet from opposite directions, the elevation of one coincides with the depression of the other, they neutralize each other, and the surface of the fluid remains level ; but, beyond their place of meeting, the waves again appear moving onwards in their original direction.

When parallel waves coming from different, but not directly opposite directions, intersect each other, both the effects above mentioned are produced at different points. Thus, if we suppose the continuous lines in fig. 120 to represent the elevations of the undulations, and the dotted lines the depressions, elevations of double height will be produced where the continuous lines cross, and depressions of double depth where the dotted lines cross each other ; while, at the points where the continuous lines intersect the dotted lines, the elevation of the one wave will neutralize the depression of the other, and the surface will remain undisturbed. This is the “interference” of waves.

Waves are reflected by the surfaces of solid bodies ;

Fig. 121.



and in the case of a wave, as of a ray of light, the angle of reflection is equal to the angle of incidence. If a wave be imagined to consist of a series of forces moving forwards side by side, each part of the wave will be reflected by the solid surface at the same angle as that under which it impinged on the surface, and thence will result a system of reflected portions of waves which will together form a reflected wave. The direction of the reflected wave may be either the same or different from that of the original wave. The reflected and incident waves have the same direction, when straight waves are produced in a channel, as above described, and when these waves impinge in a perpendicular direction on the reflecting surface, and also when circular concentric waves issuing from one point strike upon a surface which itself forms a concentric circle around that point; in the latter case the reflected waves move back again towards the central point whence they arose.

A circular wave or undulation is reflected from a plane surface in the direction which a wave would have, that issued from a point at the same distance behind the surface as the central point of the original wave lies in front.

Waves originating at one focus of an ellipse, and falling upon a surface occupying the periphery of this ellipse, are reflected in such a manner that the central point of the reflected waves is the other focus of the ellipse; for each point of a wave originating at one focus of an ellipse will, according to the law of equal angles of incidence and reflection, be reflected towards the other focus of this figure. For the same reasons, circular waves issuing from the focus of a parabola, and impinging upon a surface occupying the periphery of the parabola, are, by virtue of the properties of that figure, reflected in straight lines, and in a direction parallel with the axis of the parabola.

On the other hand, straight waves moving in a direction parallel with the axis of a parabola must be reflected by the parabolic surface, as concentric waves having the focus of the parabola as their common centre.

Circular waves, therefore, originating at the focus of a parabolic surface, and reflected by this surface as straight waves in a direction parallel with the axis of the parabola, will be reflected by a second parabolic surface placed directly opposite to the former as concentric waves meeting in the focus of the second parabola.

If waves are produced in water by an impulse communicated to its surface in the whole length of a line, every point of this line may be regarded as the centre of a circular wave. These waves issuing from all the points of the line of impulse at the same moment will remain all of equal size as they extend outwards from their respective centres, and, intersecting each other, will give rise to the production of a larger straight wave (*a* and *b*, fig. 122), before and behind the line of impulse, and parallel with this.

A body moving through the water gives rise to a constant succession of circular waves (fig. 123). Those last produced are small; while the others at a greater dis-

Fig. 122.

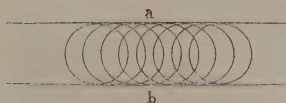
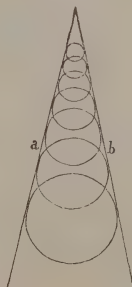


Fig. 123.



tance behind the moving body are larger and larger in proportion to the length of time that has elapsed since their production; and, in consequence of this, the larger waves which they produce by intersecting each other at the sides (*a* and *b*) diverge from the body which gives the original impulse.

Waves passing through an opening in any solid body do not retain the form which they had in the opening: on the contrary, their extremities which have passed the margins of the opening receive a circular inflexion around these margins, in consequence of which the waves, after their exit, not merely extend forwards, but also in the lateral direction. This is the "inflexion" of waves.

Stationary waves or vibrations.—If *A* (fig. 123) represents a wave upon the surface of a fluid, *a b c* the depression of this wave, *c d e* its elevation, and *e* the surface of a solid body against which the wave impinges, a period will occur at which, as at *A I*, half the length of the elevation, or one-fourth the length of the entire wave, will have reached the reflecting surface, and the wave will have the position *a b c d*, *A I*. The first half of the elevation of the wave will then be already reflected, and the half elevation seen in contact with the reflecting surface will consist of a progressive half-wave *c d*, and a reflected half-wave *d' e'*: it will therefore be higher. After a second similar period of time has elapsed, the wave in its progress towards the surface will have reached the limit between its elevation and depression, and its whole elevation will be reflected, as at *A II*, where *a b c'* is the depression of the wave, *c' d' e'* the reflected elevation. The elevation and depression will therefore obliterate each other, and the surface will at this period be even.

After the lapse of a third period, half the depression of the wave only (*a b*, *A III*,) remains, the other half will have been reflected, *b' c'*, and the elevation of the wave previously reflected, *c' d' e'*, will have advanced half in length in the retrograde direction. After a fourth similar period has elapsed, the second half of the depression of the wave will also have impinged on the surface and have been reflected, *A IV*, *a' b' c'*, and the reflected elevation *c' d' e'* will have reached the distance of its entire length from the reflecting surface. The position of the wave is now therefore the same as at first, only the relative situation of its elevation and depression is reversed; the depression occupies the place of the elevation, and the elevation that of the depression, as shown in the last diagram of the figure.

If, now, the first wave *a b c d e* (fig. 124, *B*) is followed by a second *x a*, the position which they will hold after the first period has elapsed, is represented by *B I*, that which they will have after the second period, by *B II*; that after the third,

Fig. 124.

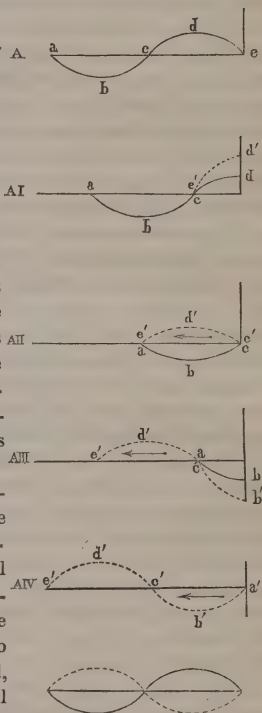
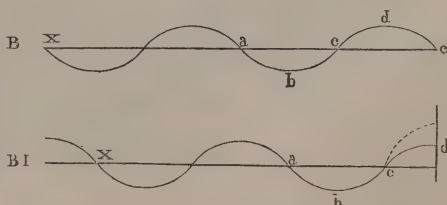
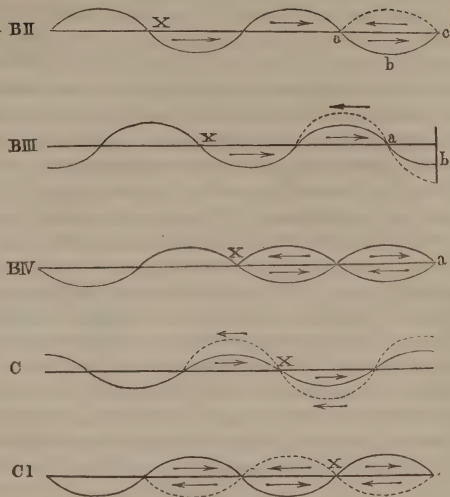


Fig. 125.



by B III. The elevation of the second incident wave, and that of the first reflected wave, are now coincident, and the elevation is consequently more considerable. After the fourth period, the elevation of the second incident wave will coincide with the depression of the first reflected wave, and *vice versa*, as at B IV. At this moment of time, therefore, the surface will be even. After the next period, each wave, the incident and reflected, will have advanced the extent of one-fourth of its length; or, in other words, the parts of the waves which were before coincident have become separated by half the length of



a wave: the form of the surface will therefore be as represented at C, where the depressions are again coincident with each other, and the elevations also producing a deeper depression and a higher elevation. After the following period, the depressions will again coincide with the elevations, as at C I. These waves, recurring at regular intervals, are called stationary waves, or stationary oscillations. Their elevations and depressions do not move in a progressive manner from one part of the surface to another; the movement in the vertical direction only remains. They are alternate vertical elevations and depressions of the surface, resulting from the meeting of progressive waves from opposite directions.

Stationary oscillations or waves are produced in the straight channel by exciting a succession of waves at regular intervals of time, which are then reflected at the opposite extremity of the channel; or, in a circular vessel, by exciting waves from its centre by impulses repeated at regular intervals. The MM. Weber also observed the stationary waves in vessels filled with fluid, and placed upon a drum or a cane chair, when impulses were given to the elastic surface at regular intervals.

B. Undulations of inflexion or flexion-waves in solid bodies.—The cause of the undulations of this kind in fluids is the force of gravity; in solid bodies it is the force of cohesion and elasticity. These undulations are much quicker in solid bodies than in water, and in elastic bodies are the cause of sound.

If a stretched cord or string of a musical instrument is struck, not at its middle, but near one extremity, an extension of it is produced at this part, and is communicated as a wave or oscillation to the whole cord, travelling from one end to the other where it is reflected back again like the undulations of fluids.

If the cord or string is struck several times in succession, a regular series of undulations is produced, as upon the surface of water. The reflection of these undulations at the extremity of the cord, and the meeting of the incident and reflected undulations, give rise to the stationary vibrations; and the parts of the cord which remain at rest between these stationary waves or vibrations are the "nodal points."

The simplest stationary vibration of a cord or string is, however, that which re-

sults, not from the meeting of progressive undulations, but from the transverse vibration or movement from side to side of the whole cord between its fixed extremities, which here constitute the nodal points. This kind of vibration is induced most readily by striking a string with the finger, or with a violin-bow. The transverse oscillation of solid bodies which do not owe their elasticity to tension, such as metal rods fixed at one extremity only, is also an instance of stationary vibration.

C. Undulations of condensation in liquids, gases, and solid bodies.—The undulations of inflexion in water are not attended with any condensation and rarefaction, nor are they necessarily so in a cord or string. If the cord is not extensible, or not elastic, the undulations of inflexion may be produced by the mere displacement, and the striving of the parts of the cord to regain the straight direction. Generally, however, the waves of inflexion in strings are attended with alternations of condensation and rarefaction. The peculiarity of the undulations of inflexion consists in many parts of the body having imparted to them so considerable a movement in the direction perpendicular to its surface, that the form of the surface undergoes a visible change. All bodies become the seat of undulations of condensation, on the contrary, when, by an impulse communicated to them, their most minute constituent parts only are in succession thrown into motion, the impulse being imparted from one particle to another. Hence these undulations are sometimes called undulations of the progressive impulse. By the impulse of the molecules moved upon those in front of them, condensation is produced; and this is necessarily accompanied by a rarefaction behind it. The movement thus propagated from particle to particle is so slight, that no change in the surface of the body is visible; just as an impulse is propagated through a row of solid balls, while these balls themselves retain their original place.

The direction of the movement induced in the particles by the impulse may in a rod or string be different from that in which the undulation is propagated. If, for example, a rod or string, a, b , is a ————— b struck at a point near a , in a direction perpendicular to its length, the particles immediately set in motion by the impulse induce a similar movement—namely, a movement in a direction perpendicular to the length of the rod a, b ,—in the particles next to them, these again in others next to them, and so on to the other end, b , of the rod or string. All the particles of the rod or string between a and b are, therefore, successively moved, or thrown into a state of condensation in the perpendicular direction;—that is to say, an undulation travels in the direction from a to b , while the movement of the particles themselves, induced by the impulse, has a totally different direction,—namely, a direction perpendicular to a, b . If the middle of the rod is struck, the undulation is propagated in two directions; towards a , and towards b . Similar undulations are produced also in a broad plate, as Savart has shown.*

The propagation of an impulse in bodies occupying a cubic space, as in rocks, or masses of air and water, takes place in all directions. The propagation of sound, in all bodies, is effected by the propagation of the impulse or waves of condensation.

Undulations excited in the air consist of progressive condensations and rarefactions. The part where the condensation exists is analogous to the elevation; that where the rarefaction is, to the depression of an undulation of inflexion. A progressive undulation travelling through a column of air in a tube is reflected at the extremity of the tube if this is closed, and in its retrograde course retains its original properties. The wave is also imperfectly reflected even when the extremity of the tube is open; but, experience has shown that in that case the properties of the un-

* Compare Weber, *op. cit.* p. 440.

dulation are reversed, its rarefaction taking place where its condensation should be, and *vice versâ*. Undulations in the open air have a spherical form.*

II. *Of the stationary and progressive undulations of sonorous bodies.*

The vibrations of sonorous bodies are either undulations of inflexion, or undulations of condensation. Either of these kinds of undulations, or both simultaneously, may take place in strings and solid bodies which give sound. Columns of air, in yielding sound, are the seat of undulations of condensation only. The undulations of sonorous bodies may be either stationary or progressive. If a tense string is drawn out of the straight line at its middle, and then left to the force of its elasticity, no progressive undulations are observed to take place in it,—at least not distinctly. On the contrary, the string vibrates from side to side, like a pendulum, in the whole extent of the curve which was given to it, or in its whole length. After being drawn out of the straight line, it strives to resume this line by virtue of its elasticity; but the force by which it is moved carries it beyond the straight line to the opposite side, and this is repeated until it gradually returns to its state of repose or equilibrium. This is a stationary vibration.

The rate of the vibrations of stretched strings, or the number of the impulses which they impart to the air, increases in an inverse ratio with their length, and in a direct ratio with the squares of the extending forces. Thus a string which performs one hundred vibrations in a second of time, if reduced to half the length, will vibrate two hundred times in the same period, the extending force being equal; or, its length remaining the same, if it performs one hundred vibrations with an extending force of one loth [half an ounce], it will vibrate two hundred times when the extending force equals four loth, four hundred times when the extending force is sixteen loth.

Sonorous rods are also susceptible of stationary vibrations, the number of which in a given time will be in a direct ratio with the thickness of the rods or bars, and in an inverse ratio with the squares of their length.

Under certain circumstances a progressive movement of the summit of the undulation is combined with a stationary transverse vibration, without any change in the rapidity of the transverse vibrations being thereby induced: for instance, when a string is struck near one of its fixed points, it not merely performs transverse vibrations, such as it makes when struck at its middle,—that is, transverse vibrations equal in length to the whole length of the string,—but the summit of this stationary undulation travels to and fro from one end of the string to the other, being reflected by each of its fixed points. The number of vibrations of a string thus vibrating is exactly the same as that of a string the summit of whose vibrations remains constantly in the middle; and as the acute or grave character of a sound, or its pitch, always depends on the number of vibrations performed within a certain time, the “pitch” of the note produced is in both cases the same, but the “tone” is somewhat different. This is an important circumstance in relation to the theory of the “tone,” or quality of different sounds.

Stationary undulations or vibrations are produced also when, by touching lightly a stretched string, we give rise to a nodal point in that situation, and then strike the part of the string thus isolated. If, for example, the string is touched at its middle, and either its upper or its lower half then struck with the violin-bow, not merely does the half that is struck become the seat of transverse vibrations, but the other half also vibrates from side to side, though in the opposite direction. The number of the vibrations in a given time is in this case twice as great as when the string vibrates in

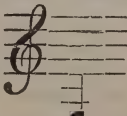
* Weber, op. cit. § 276.

its whole length, and the sound produced is the octave of the fundamental note of the string. If the string is touched at the point of junction of its first and middle third, a nodal point is formed between its middle and last third also, and the number of the vibrations is three times as great as that of the vibrations of the entire string within the same period. In the same way, by isolating and striking a fourth or fifth of the string, a regular division of the string into four or five vibrating portions, separated by nodal points, is induced. Pieces of paper placed upon these nodal points during the vibration of the string are not thrown off. The sounds resulting from the vibration of a string thus divided by nodal points are called "harmonic notes."

Plates or disks thrown into vibration by means of a violin-bow divide into four, six, or eight segments, which vibrate in opposite directions, and are separated from each other by nodal lines, on which sand strewed over the surface remains at rest. Lightly touching the margin of the plate at any point gives rise to a nodal line there, and this determines the situation of the other nodal lines. The second influential condition is the part at which the margin of the plate is struck with the violin-bow; for this becomes a vibrating portion, and determines the situation of the other vibrating segments. In this way are produced the symmetrical nodal figures of sonorous vibrating surfaces, described by Chladni.

Both stationary and progressive undulations of elastic bodies are adequate to the production of the phenomena of musical sounds, if they are regularly repeated; for even the stationary vibrations become progressive undulations when communicated to conducting media: each stationary vibration excites in the air, in water, or in solid bodies capable of conducting sound, a progressive undulation.

Sounds may be produced in solid bodies, as well as in columns of air in tubes, by progressive undulations of condensation. Rods may be thrown into longitudinal undulations of condensation and rarefaction by friction in the longitudinal direction. These progressive undulations of condensation, without any transverse vibration, may likewise produce sound in a stretched string. The time occupied by the progress of the undulation from one end of the string to the other, and back again, on which depends the number of the undulations excited in the air, is of course determined by the length and tension of the string. These longitudinal undulations do not, however, maintain the requisite strength, and are not of sufficient duration to produce sounds, unless the impulse be constantly repeated. This constant repetition of the impulses is supplied by friction. By a modification of these impulses the rapidity of the longitudinal undulations may, indeed, be influenced. This is exemplified by the longitudinal vibrations which Chladni excited in strings by friction in the longitudinal direction. The sounds yielded by the strings of the Æolian harp appear also to arise from vibrations of this nature: according to Pellisov,* they are attended with no perceptible transverse vibration; and variations in the strength of the current of air give rise to different harmonic notes, without any nodal points being apparently formed. Pellisov has further described a mode of proceeding, by which very different notes may be obtained from a violin string, of which the tension remains the same, without the developement of nodal points. It consists in laying the bow upon the string (which should be two feet in length, and one-third of a line thick, and

tuned to G treble below the line , close to the bridge, and drawing it

across the string, at first as lightly as possible, and with one equable movement. The

* Poggendorf's Annal. xix. 237.

sound produced then varies in pitch entirely in accordance with the strength and rapidity of the stroke of the bow; and not merely can those notes be easily produced which the wind is capable of producing in the *Æolian* harp,—namely,

G, D, G¹, B¹, D¹, E¹, G², A²,

but also most of those intermediate between them and other higher notes. The undulations in the production of the sounds thus excited travel, according to Pellisov, from the molecules immediately acted on by the bow to the other extremity of the string, and are there reflected. By a particular manipulation of the bow he was able to obtain notes which were lower in pitch than the fundamental notes of the strings, and were, therefore, certainly not due to transverse vibrations.

Pellisov goes still farther; and maintains that, even when the string vibrates in the transverse direction, the sound produced is not due to the transverse vibrations, but to the undulations of condensation and rarefaction (called also molecular vibrations) which travel up and down the string. According to the view generally adopted, these minute undulations, originating at the part of the string which received the impulse, and communicated thence by virtue of the property of elasticity to the whole string, are of importance only so far as they have for their result the transverse vibration of the whole string between its fixed extremities, or between its nodal points. Pellisov maintains that the contrary of this is the fact; that the pitch of the sound depends on the rapidity with which the ultimate particles of the sonorous body, whether string, column of air, rod, or plate, vibrate; and that the vibrations of the string, column of air, or plate, or of their larger segments, contribute to the result in no other way than by determining the rapidity of the molecular vibrations. According to this view, therefore, a string vibrating transversely would produce no sound, unless at the same time its individual constituent molecules were vibrating,—that is to say, unless progressive undulations of condensation were travelling to and fro between the nodal points of the string.*

Though the correctness of the hypothesis of the transverse vibrations of strings being incapable of producing sound cannot be admitted as proved, yet the simultaneous existence of the transverse vibrations, and of the progressive undulations of condensation and rarefaction in sonorous bodies, may serve to give us a very good idea of the mode of production of several different sounds simultaneously by one body. A vibrating string is prone to yield, besides its fundamental note, another fainter sound, a harmonic of the other; as the fifth, or the third of the higher octave. The fainter sounds accompanying the principal sound of a bell are well known.

The column of air in pipes is susceptible of no transverse vibrations, but merely of the progressive undulations of condensation, which travel to and fro along the length of the tube. The blast is continuous; but the effect which it produces is intermittent. The number of undulations within a given time, or, what is the same thing, the length of the undulations, is determined by the length of the column of air.

A gentle blast gives rise to the fundamental note of a covered pipe, in which case the nodal point lies at the extremity of the column of air. The same blast causes the developement of a nodal point in the middle of the column of air in an open pipe, and the note produced is consequently an octave higher. By blowing with greater force, the column of air is made to subdivide itself still further, and higher notes are the result. (See page 978.)

We have lastly to explain the difference which obtains between a mere “noise,” a “report,” a “continued sound not of musical character,” a “musical sound,” and “tone.” Any impression upon the organ of hearing by an undulation, or

* Pellisov, loc. cit.—Fechner, *Repertor. der Experimental Physik*, i. B. p. 256.

several undulations, communicated to it, gives rise to a sound or noise. This sound, when produced by a single impulse, is short in duration; and, if intense, has the character of a "report." The intensity of the sound depends on the extent of the excursions of the vibrating particles. The "quality" may be very various. Wood, pasteboard, and metal produce each a sound of different quality. The quality of the sound appears to depend partly on the form of the undulations, and partly on the simultaneous existence of undulations of different rapidity. One and the same body, if it possess unequal elasticity in different directions, may, on receiving an impulse, become the seat of undulations of different rapidity in different parts, and will communicate these undulations to a conducting medium, not simultaneously, but at more or less distinct periods, producing thus in the latter a compound wave of peculiar form. This compound wave, or sum of waves, is transmitted to the organ of hearing in the same order and form as it was received by the conducting medium, in which all modulations are propagated with equal rapidity.* The circumstance, also, that a body may be affected with a transverse and longitudinal vibration at the same time, has a share in the production of the quality of a sound. A string struck with the finger near one extremity vibrates in the transverse direction in its entire length; but, at the same time, the summit of the undulation travels alternately from one end of the string to the other. Hence the quality of the sound yielded by the same string, though its length and tension remain unaltered, may vary somewhat according to the part at which it is struck. Lastly, the form of the wave is modified, according to Pellissier and Eisenlohr, by the density of the body which is its seat. In a dense body the aberration of the vibration is less considerable than in a body less dense. The particles of air in contact with it receive the impulse from it more simultaneously, and the rarefied space which it leaves by its contraction after giving the impulse is smaller. If the density of the sounding body, in fine, be unequal, the condensations and succeeding rarefactions which it imparts to the air, must also be unequal.

If several undulations succeed each other, a more or less prolonged sound results, which may or may not have a musical quality. A succession of similar or dissimilar short sounds, at unequal intervals, gives rise to various unmusical sounds or noises. A succession of short sounds, even at equal intervals, if the individual sounds are distinguishable, does not produce a musical sound. For the production of a sound of musical character, it is necessary that the succession of separate sounds or impulses be not recognizable. The height or pitch of a musical sound depends on the rapidity with which the separate impulses succeed each other. Savart's experiment with the toothed wheel illustrates the mode of production of musical sounds: as long as the separate strokes of the teeth can be heard, the sound has not a musical character; but acquires it when they are made to succeed each other more rapidly, although the unmusical quality of the sounds resulting from the impulse of the separate teeth is still heard. A continued sound of definite musical value may therefore result, not merely from a regular succession of simple waves or vibrations, but also from a regular succession of very compound undulations, such as separately constitute short unmusical sounds. A full and pure musical sound requires for its production simple undulations of sufficient strength without the irregular intermediate undulations. The quality of "tone," or "timbre," possessed by a musical sound, is dependent on the same causes as the quality of a simple sound not musical; the musical sound differs merely in the undulations which produce it, succeeding each other at regular intervals.

* Eisenlohr, *Lehrbuch d. Physik*, p. 151.

III. *Of the undulations by which sound is propagated.*

*Of the progressive undulations engaged in the propagation of sound.**—The propagation of the vibrations of sonorous bodies is effected ordinarily by undulations of condensation and rarefaction, not by undulations of inflexion. Sonorous vibrations are propagated even in water by means of undulations of this kind; by a movement, therefore, very different from the undulations of elevation and depression of the surface of the water.

An impulse in every direction imparted to the air at one point gives rise to a spherical wave of condensed air, of the form of a hollow sphere, which extends equally in all its dimensions, maintaining consequently its spherical form. A spherical body suddenly expanding in the air would excite such a wave. The particles of air which receive the impulse from such a body thus suddenly expanding, acquire at first a motion in a direction corresponding to that of the impulse,—namely, in the direction of the radius of the expanding sphere; and, subsequently, when the expanding body contracts again and produces a rarefaction around it, a motion in the opposite direction. All the particles of the air traversed by the spherical wave, or undulation, experience the same movement. The extent of the forward and retrograde motions of the particles of air, which is to be regarded as the same thing as the height of the elevation of the undulations on the surface of water, decreases with the progress of the wave, while the thickness of the wave remains the same, just as a circular wave excited upon the surface of water becomes lower as it extends itself, though its breadth remains unaltered. The cavity of a spherical wave increases uniformly in diameter; and its circumference consequently increases as the square of its diameter. The elevation of the undulation decreases in the same ratio. This is the cause why the intensity of a sound diminishes, in the open air, in an inverse ratio with the squares of the distance from its origin. In the motion of the air in a tube no cause for the diminution of the intensity of the sound exists.

If the impulse is imparted to the open air by a solid body, not in every direction, as in the case of the spherical body suddenly expanding, but in one direction only, the wave produced is still spherical, just as a wave excited upon the surface of water by a blow in any one direction extends in all directions, and is consequently circular. The height of the elevation of the wave, or the extent of the to and fro movement of the particles of air affected by the undulation, is, however, greater in the direction corresponding to that of the impulse. Hence, if the undulations in a sonorous body, as a vibrating string or column of air, have a determinate direction, the sound will be heard more distinctly and with more intensity in that direction. It appears to me, that in some cases the following circumstances also may contribute to this effect. The wave produced in a medium capable of sonorous undulation by an impulse acting upon it over some extent, may be regarded as compounded of a number of circular undulations of equal diameter lying side by side. To the extent to which the impulse reached, and in lines parallel with the line of its application, these circular undulations coincide with and strengthen each other, but beyond that extent such is not the case. The action of the wave will, therefore, be stronger in the direction perpendicular to the line on which the impulse acted than in other directions.

The intensity with which sounds are conducted depends, *cæteris paribus*, on the relation existing between the sonorous body and the conducting medium. The more the latter resembles in its physical properties the body which yields the sound, the more perfectly will it conduct it, and *vice versâ*. The column of air of a wind instrument, for example, communicates its sonorous vibrations in such perfection to the

* After Weber, op. cit. p. 501.

atmosphere, that the interposition of other media does not tend to increase the intensity of the sound; while to solid bodies, on the contrary, the vibrations of a column of air are not readily communicated. On the other hand, solid bodies impart their vibrations imperfectly only to the air, and in all their intensity to other solid bodies. Moreover, sonorous undulations, in their transition from one medium to another different medium, are, like rays of light, partly reflected. These considerations afford an explanation of the interruption offered by rocks to sounds excited in the air, and of the circumstance that the sonorous vibrations of a solid body, such as a rod, are communicated to the ear with greater intensity by means of a cord than through the intervention of the air. Mr. Wheatstone states,* that by means of a wire the sounds produced by a stringed instrument may be conducted to a resounding body placed at a considerable distance.

Resonance is a means of rendering a sound louder than it is as produced by the sounding body itself. It consists in increasing the extent of surface of a soniferous medium similar in kind to the sounding body. Hence the increase of sound produced by placing a vibrating tuning-fork upon a solid body. The influence of the bridge and sounding-board of stringed instruments is due to the same principle. Greater resonance is, however, produced by an insulated body than by one which has no circumscribed surfaces; for an insulated body reflects back a part of the undulations within it at its borders and surfaces, and, these reflected undulations meeting with the undulations newly excited in it, an increased extent of the excursions of the oscillating particles, answering to the increased height of the elevations of flexion-waves, is produced. (See pages 1218 and 1219.)†

Stationary vibrations in bodies conducting sound.—Stationary vibrations are developed in bodies to which sonorous vibrations are communicated, and which are insulated, and at the same time elastic. We have stated that progressive sonorous undulations in an insulated body are reflected at its borders and angles; and that, in consequence of this, the undulations newly communicated to the body, and those reflected within it, meet and intersect each other. When sonorous undulations are communicated from one body to another, the breadth of the separate undulations in the second resounding body is not determined by this body,—they are not necessarily aliquot parts of it; but their breadth is determined by the body originally producing the sound, in which the undulations always correspond to aliquot parts of itself. An insulated body, to which sonorous vibrations are imparted from another body, may, however, divide into several segments by the development of nodal points and nodal lines. Savart's experiments have shown, for example, that such nodal lines are formed in tense membranes, while conducting sonorous vibrations, and are seen when a light powder is strewn upon the surface. Metallic or glass laminæ also present the same phenomenon when they are brought, by means of a rod, into connexion with a body emitting sound.‡

The sound of one body may, under certain conditions, excite in another insulated elastic body not merely resonance, but also a new production of sound; the sound emitted by the body thus secondarily thrown into sonorous vibration, being in this case the note peculiar to itself, and different from that produced by the body primarily affected. Stretched strings will reciprocate the sounds of other bodies by the notes for which their degree of tension fits them; for this to occur, it appears to be necessary not merely that the sonorous body secondarily affected be very elastic and bounded by

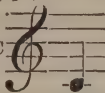
* Ann. de Chimie et de Phys. t. xxiii. p. 317.

† Weber, op. cit. p. 536.

‡ On the difference in the nodal figures produced on bodies in which the vibrations are primarily excited, and on those vibrating by reciprocation, see Weber, op. cit. p. 541.

free surfaces, but also that the number of the vibrations in the note which it is adapted to yield should bear a simple numerical relation to those of the original sound.

Finally, an elastic sonorous body of definite extent may, under certain conditions, even modify the pitch of the sound yielded by the body primarily thrown into sonorous vibration; the vibrations of each reciprocally influencing those of the other, so as to give rise to undulations which differ from those proper to either separately. Thus, the column of air of a tube combined with a reed modifies the pitch of the sound yielded by the latter (see page 985). I have observed another remarkable example of this reciprocal influence of sonorous vibrations of different bodies in a pipe, the open end of which I had closed with a membrane (of pig's bladder). A one-foot mouth- or flute-pipe, closed at one extremity with a plug, has, it is known, for its fun-

damental note C ; but when the pipe, instead of being thus closed, had its

extremity merely covered with a membrane loosely stretched over it, the note yielded with the feeblest blast was from a "third" to a "fifth" deeper than this C: in proportion as the membrane was made more tense, the note became sharper; and, when it stretched as tightly as possible, it acted like the solid plug.

Fluids capable of propagating sonorous vibrations present, when in immediate contact with bodies emitting sound, peculiar undulations of inflexion on their surface, which ought to be distinguished from the undulations of condensation by which they propagate the sound. Their surface presents small wave-like elevations and depressions very regularly arranged, like stationary undulations or vibrations. These appearances have been described by Oersted, Purkinje, Chladni, W. Soemmering, and Faraday.*

If a tuning-fork, of which one side is covered with a thin layer of water, be held horizontally with this side uppermost, and be allowed to vibrate freely in the air, the water on its surface will be seen to become affected with most beautiful parallel stationary undulations, which generally occupy the entire breadth of the tuning-fork, and are about three-fourths of a line in length. They are, as it were, impressions of the vibrations of the sounding body, produced by the impulses imparted by those vibrations to the particles of water. If the tuning-fork be held with one of its surfaces immersed in a basin of water, the surface of the water at its sides will be seen to become the seat of very regular parallel divisions, just as if the water in contact with the tuning-fork were thrown simultaneously with it into a movement of undulation, and as if its undulations were prolongations of the undulations of the fork. If the broad surface of the tuning-fork, covered with a thin layer of water, be raised above the surface of the water of the basin, and its sides only be immersed, it will become evident that the undulations of the water on the surface of the tuning-fork, and those of the water in the basin, are prolongations of each other. It is a remarkable circumstance, however, that, whichever surface of the fork is immersed in the water, the stationary undulations of the water that are produced, always abut perpendicularly upon the surface of the fork. The only deviation from this law is observed at the angles of the instrument where the lines of the undulations become divergent.

The same phenomenon is observed in musical glasses filled with water: such a vessel being thrown into sonorous vibrations by means of a violin-bow, the surface of the water is seen to divide itself into several compartments (four, six, or

* See Chladni and W. Soemmering, in *Kastner's Archiv. für die gesammte Naturlehre*, B. 8, p. 91.—Faraday, *Philosoph. Transact.* 1831. 319.

eight, according to the height of the note produced,) separated by nodal lines, between which, if the stroke of the bow was gentle, stationary undulations are seen directed perpendicularly against the internal surface of the vessel. If the stroke of the bow was stronger, other figures are produced; and, by the decussation of undulations having different directions, rhomboidal stationary undulations are developed. The water, moreover, accumulates in the vibrating segments, and is spirted out of the vessel when the action of the bow is violent. If the glass vessel is thrown into vibration by the friction of the finger upon its margin, the vibrating segments and the nodal lines move round in a circle, following the movement of the finger.

The application of the violin-bow to the border of a lamina of glass, of which the surface is covered with a thin layer of water, gives rise to the same phenomena in a still more marked degree.

If to the parchment of a drum a piece of cork be fastened, and to this a rod of wood terminated at its other extremity by a round or square lamina, and if the drum be so placed that this wooden plate dips lightly into the surface of some water, the vibration of the membrane of the drum will be found to give rise to similar stationary undulations in the water, which have a direction perpendicular to the margin of the wooden plate; so that, when this is of a circular form, a starlike figure is produced on the surface of the fluid. A satisfactory explanation of the phenomenon cannot at present be given.

Dr. Faraday says, in explanation, that the slightest possible difference in any circumstance during the vibration of an elastic plate is adequate to produce an elevation or depression of the fluid, and thus give the first impulse to the phenomena; but I cannot imagine that such regular phenomena can be explained in this way, without reference to a regular division into segments, or to the vibrations of the sounding body, although these considerations do not at present afford us a satisfactory theory.

The undulations on the surface of water, to which we have been just referring, are undulations of elevation or inflexion; but the undulations by which sound is conducted in water, as in the air, are undulations of condensation.

The rapidity with which sound is propagated depends on the density and elasticity of the body. The rapidity in dry air, at a temperature of 32° Fahr. is at the rate of 332·49 metres, or 1022·194 feet (Parisian measure), [or about 1090 feet English measure] in a second. Its rapidity increases with the rise of temperature. Sound is propagated in water with about four times greater velocity than in air; in solid bodies its rapidity of transmission is still greater. Iron propagates sound with ten and a half times, wood with eleven times, greater rapidity than atmospheric air.

Reflection of sound.—In relation to their reflection, the undulations of sound resemble those of light; in passing from one medium into another different one, they are in part reflected, and in part only propagated onwards. The ticking of a watch placed in the focus of a concave mirror may be heard in the focus of another mirror placed so as to receive and concentrate the reflected sonorous undulations. It is owing to sonorous vibrations of air being propagated with more facility in that medium than they are imparted from it to solid bodies, that sounds are transmitted in their full intensity through tubes, just as on the same principle solid rods propagate sonorous vibrations to great distances almost without any loss of intensity. A *speaking-trumpet* represents a parabola, in the focus of which the sound is excited. Being reflected by the parabolic surface, the sonorous undulations are all thrown in a direction parallel to the axis of the parabola (see page 1217). The cause of the increased intensity given to the sound by the *speaking-trumpet* is, for the most part, the coincidence of newly excited undulations with others already reflected, producing undulations with greater condensations and rarefactions. But the resonance of the confined mass of air in the tube also contributes to this effect; for the air of a tube open at both extremities, while it propagates sound, also becomes the seat of resonance.

The *ear-trumpet* becomes narrower towards the ear, and consequently concentrates the sonorous undulations. If its walls have the parabolic form, and the focus of the parabola be at a point near the ear, sonorous undulations coming in a direction parallel with the axis of the parabola will of course be brought to a focus near the ear.* If a reflecting surface is situated so as to throw sonorous undulations upon the ear, and is at such a distance that the reflected undulations reach the ear perceptibly later than the undulations coming direct from the sounding body, an echo results, which is perfect when the difference of time is so great that the two series of undulations strike the ear at perfectly distinct periods.

CHAPTER II.

OF THE DIFFERENT FORMS OF THE AUDITORY APPARATUS, AND OF ITS ACOUSTIC PROPERTIES.

1. *Of the different forms of the organ of hearing.*

IN the greater number of invertebrate animals there are no parts known which can be regarded as analogous to the organ of hearing of the higher classes; and in the case of many animals it may be doubted whether they really hear at all; for every reaction of nerves under the influence of vibrations cannot be called the sensation of sound, since the sense of touch is capable of perceiving the same vibrations as a tremour.†

In all cases the first essential of an organ of hearing is the special nerve endowed with the property of perceiving impulses as sound; and, next to this, an apparatus adapted for conducting these impulses to the nerve. Inasmuch, however, as all matters have the property of propagating sonorous vibrations as undulations of condensation, it is evident that a special apparatus for conducting these vibrations may be absent; and this enables us to understand why no special auditory apparatus has been hitherto found in many invertebrate animals. The auditory nerve, if merely in contact with the solid parts of the head, will be as certainly affected by the vibrations communicated to those parts as if it were spread out in a special organ.

The simplest form of the organ of hearing in which a special apparatus is added to the nerve with the specific endowment, is a small sac containing fluid, with the auditory nerve expanded upon it. The sonorous vibrations are communicated to this organ, either through the medium of the hard parts of the head alone, or at the same time by the contigu-

* Eisenlohr, loc. cit. p. 164.

† For an account of the parts regarded as organs of hearing in insects, see Compagretti, *Obs. Anat. de Aure Interna Comparata*; Patavii, 1789: Treviranus, *Ann. d. Wetterauschen Gesellschaft*, B. i. 2; Frankfort, 1809, p. 169: Ramdohr, *Magazin d. Gesellschaft Naturforschender Freunde*; Berlin, 1811, p. 389: J. Müller, *Physiol. des Gesichtsinnes*, p. 437.

ous hard parts, and by a membrane lying freely exposed to the surrounding medium. This is the form of the organ of hearing in the Crustacea among the Articulata, and in the Cephalopoda among the Mollusca.

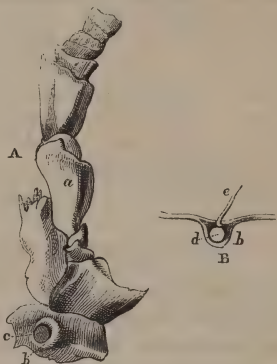
In the Crustacea this organ lies at the inferior surface of the head on each side, in the basilar segment of the outer great antenna. It consists of an osseous vestibulum, the external opening or fenestra of which is closed by a membrane analogous to the membrana tympani secundaria fenestræ rotundæ of the higher animals (fig. 125, A). In the interior of this osseous cavity lies a membranous sac filled with a watery fluid, upon which the auditory nerve is expanded (fig. 125, B).

The Cephalopoda have a cartilaginous vestibule, which is a mere excavation in the cartilage of the head, devoid of fenestra or external tympanum-like membrane. This cavity encloses a membranous sac, over which the auditory nerve distributes itself. In the Octopus the inner surface of the vestibule is smooth; in the Sepia and Loligo it is beset with soft knots or processes, by which the interior vesicle is held suspended. Within the vesicle is a hard concretion or otolite.†

The organ of hearing in the Vertebrata is in no instance so simple as in these invertebrate animals. It was formerly thought that the Petromyzon resembled the Invertebrata in this respect; but my researches have shown that they possess a complicated labyrinth with two semicircular canals. In tracing the organ of hearing from fishes up to Mammalia, we find it present a progressive developement and increasing complexity.‡

In fishes the cochlea and tympanum of the higher Vertebrata do not exist; but they have the membranous labyrinth,—namely, the alveus s. sinus communis canalium semicircularium, (the oblong portion of the membranous vestibule or sacculus oblongus, into which the semicircular

Fig. 125.*



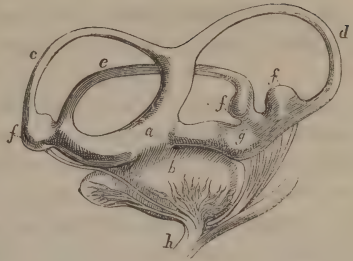
* [Organ of hearing of the *Astacus fluviat.* after Weber.—*a.* Antenna; *b.* papilla containing the organ of hearing; *c.* membrane of the fenestra; *d.* the membranous sac upon which the nerve, *e*, is distributed.]

† On the organ of hearing of the *Astacus fluviatilis* and Octopus, see Weber, *De Aure et Auditui Hominis et Animalium*. Lips. 1820, tab. 1, 2.

‡ The structure of the ear in vertebrate animals and man is fully considered in the works of Scarpa, *De Auditui et Olfactu*; Ticini, 1789: Weber, *op. cit.*: and Breschet, *Recherches Anat. et Physiol. sur l'Organe de l'Ouïe*; Paris, 1836.

canals open,)—and generally the round saccular appendage of that part (*sacculus rotundus*), and the semicircular canals (fig. 126). This membranous labyrinth either is wholly enclosed in the cartilaginous mass of the skull, as in the cartilaginous fishes,—the *Cyclostomata* and *Plagiostomata*; or lies partly in the cranial bones, and partly in the cranial cavity between the brain and walls of the cranium, as in the osseous fishes, and the families of the sturgeon and *Chimæra*.

Fig. 126.*



The following are, however, more important differences relating to the forms of this organ in fishes:—

1. One semicircular canal only, which returns into itself so as to have an annular form, and of which one part,—that namely where the auditory nerve expands itself,—corresponds to the *alveus communis* of the vestibule. This form exists in the myxinoid fishes (*Myxine* and *Bdellostoma*), and was first observed by Retzius in the *Myxine*.

2. Two semicircular canals, each of which arises from the *sinus communis* by an ampulla with three elevations. The two canals lying upon the surface of that sac converge towards each other, unite in the form of arches, and at their place of union communicate again by means of a cleft with the *sinus communis* (or principal sac of the vestibule), which has in addition a sac-like appendage. This is the form of the organ in the *Petromyzon* and *Ammocætes*.†

In these two forms of auditory apparatus no otolite exists in the labyrinth.

3. In the third form there are three semicircular canals issuing as in the higher animals, from a common vestibular sac. With this sac or *sinus communis* of the semicircular canals is connected a smaller *sacculus*, which is not analogous to the cochlea of the higher animals and man; for in them also the vestibular *alveus communis* has a sac-like appendage (the *sacculus rotundus*). Lying free in the cavity of both these sacs in fishes are either pulverulent concretions, as in

* [Organ of hearing of *Lophius piscatorius*, after Scarpa.—*a*. *Sinus communis*; *b*. the sac or *sacculus rotundus*; *c*. posterior semicircular canal; *d*. anterior semicircular canal; *e*. external semicircular canal; *f*. ampullæ of the canals; *g*. utricle of the *sinus communis*; *h*. nervous trunk from which branches are given to the sac, utricle and ampullæ.]

† See J. Müller, in the Report on the papers worthy of publication read at the Berlin Academy of Sciences, 1836; *Archiv*. 1836, lxxxiv.

plagiostomatous fishes; or hard stony bodies,—otolites or lapilli,—as in the osseous fishes.

In the Plagiostomata, (the rays and sharks,) a prolongation of the labyrinth extends to the surface, where it is covered merely by the skin.

In the sharks, the cavity of the cartilaginous vestibule merely is prolonged through the opening in the occipital portion of the skull, and reaches to the inner surface of the skin. In the rays, on the contrary, both the cavity of the cartilaginous vestibule and the membranous part of the labyrinth, are thus extended towards the surface. A hollow or depression in the middle of the occipital portion of the skull, which is covered by thin, or even by dense skin, has four openings, two on the right, and two on the left side: the posterior opening of each side communicates merely with the cartilaginous cavity of the vestibule, and is closed by a membrane; each anterior opening serves to allow the following communication with the membranous labyrinth. Between the two openings in the cranial bones and the skin lie two membranous sacs; the cavity of each of which communicates, by means of a canal which passes through the anterior opening in the cranial bones, with the sinus communis of the membranous labyrinth. This sinus auditorius externus and its canal are filled with carbonate of lime, which also exists in the form of a concretion in the alveus communis. From the part of the sinus auditorius which is united with the skin, three very minute canals pass through the skin to the surface of the body.* In the *Chimæra*, also, I found an opening in the cranium, and, corresponding with it, two attenuated spots of the skin; but the opening led into the cavity of the cranium, where a portion of the labyrinth is situated.

A communication of the osseous labyrinth with the external surface through the medium of openings in the cranium closed with membrane, is met occasionally in the osseous fishes also, but only as an exception to the ordinary structure,—for instance, in two species of *Lepido-leprus*, according to Otto,† (not in the *Lepido-leprus Norwegicus*,) and in *Mormyrus cyprinoides*, according to Heusinger.‡

Professor E. H. Weber first observed the connexion of the labyrinth with the air-bladder in many fishes.

In several genera,—as, *Cyprinus*, *Silurus*, and *Cobitis*,—this connexion is effected by means of a chain of small moveable bones. In the *Cyprini*, for example, the two membranous labyrinths, consisting of their alveus s. sinus communis, the semicircular canals, and the sac containing the calcareous body, are connected by continuity of membrane with a sinus impar, which lies concealed in the base of the occipital portion of

* *Monro, On Fishes, 1785.—E. H. Weber, op.-cit. tab. ix.*

† *Tiedemann's Zeitschrift für Physiologie, ii. pt. i. p. 86.*

‡ *Meckel's Archiv. 1826, p. 324.*

the cranium: this sinus impar is prolonged backwards on each side into a membranous atrium, which, as it lies upon the surface of the first vertebra, receives a partial osseous covering. In contact with this atrium is the first of the small auditory bones, while with the last of these is connected the anterior extremity of the air-bladder.

In the Sparoid family (as, Boops and Sargus) the anterior extremity of the air-bladder sends forwards two canals, the blind ends of which become attached to special openings of the cranium which are closed with membrane.

In the Clupeæ the air-bladder is prolonged anteriorly into a tube, which then bifurcates. Each branch enters a bony canal in the occipital part of the cranium, and here again bifurcates; each of the small tubes which result from this division dilating at last within an osseous capsule. One of these capsules contains merely the blind extremity of the prolongation of the air-bladder; but in the other a prolongation of the membranous labyrinth comes into contact with that of the air-bladder.

In the genus *Myripristis*, also, a connexion is stated by Cuvier to exist between the air-bladder and the labyrinth. The cranial cavity is closed inferiorly merely by a membrane to which the air-bladder is attached.

The tympanum and Eustachian tube, and the sinuses communicating with the nostrils in the higher animals, the air-sacs of birds, and the air or swimming bladder of fishes, belong to one class of structures. They are all cavities filled with air and formed originally as diverticula from the respiratory and intestinal mucous tract, though at a subsequent period some of them continue to communicate with those cavities or mucous tracts by ducts or openings, while others become completely insulated from them, as is the case with the air-bladder of many fishes, the original communication of which with the pharynx is closed in the course of developement.

In reptiles and amphibia, as in all Vertebrata higher in the scale than fishes, the labyrinth has one or two external openings closed with a membrane,—fenestræ, which are either simply covered by skin and muscles without having connected with them a tympanic cavity, (a disposition which may be compared to the prolongations of the labyrinth sub-jacent to the skin in some fishes,) or are in relation with a tympanic cavity containing air. The membranous labyrinth is entirely enclosed within the bones of the cranium. The fluid of the labyrinth rarely contains any lapillus or otolite, though these are found in some instances,—namely, in those Amphibia which most resemble fishes, as *Menobranchus*: generally, however, there is merely a calcareous pulp composed of microscopic crystals.

The structure of the auditory apparatus presents considerable differences in these classes. Both among the Amphibia and the reptiles there

are families in which the tympanic cavity is wholly wanting; but Amphibia are entirely distinguished from reptiles by having only one fenestra and no cochlea.

Amphibia have only the fenestra ovalis s. vestibuli, which is closed by a flat or conical stapes. The fenestra rotunda, or f. cochleæ, is, together with the cochlea, absent.

a. Some Amphibia have no tympanum. The only one of the small bones of the tympanum which they have is the flat plate of the stapes covered by muscles and the skin. The membranous labyrinth consists, as in most fishes, of the sacculus ovalis, or sinus communis of the vestibule, with three semicircular canals opening into it. Such is the structure in the Cæciliæ (Cæcilia and Epicrion), the Derotremata (Amphiuma and Menopoma), the Proteidea (Proteus, Menobranchus, Siren, Axolott, and probably also Lepidosiren), the Salamandrina (Salamandra and Triton), and in the family of Bombinator among the Batrachia or anourous Amphibia.*

b. Other Amphibia possess a tympanum. The membrana tympani here either lies free, or is concealed by the thick skin of the body; there are, besides, two or three ossicula auditus,—namely, the malleus, which is merely a small cartilaginous plate united with the membrana tympani, the bony incus, and the stapes. The Eustachian tube, a diverticulum from the cavity of the fauces, exists here, being always found where a tympanic cavity is present. The Amphibia which present this form of auditory apparatus are all the Batrachia, with the exception of the Bombinator family. These batrachian or anourous Amphibia differ, however, very much amongst themselves in the form of the external part of the auditory apparatus. They may, with reference to these differences, be classed under three heads.

1. Batrachia destitute of tympanic cavity, membrana tympani, and Eustachian tube. These are the Bombinator family, including the genera Bombinator (igneus); Cultripes, Muell. (C. provincialis); and Pelobates, Wagl. (P. fusc. Wagl. the Cultripes minor of Müller).

2. Batrachia with a membrana tympani, which is either visible externally, or is concealed under the skin; a tympanic cavity, which is for the most part membranous, three ossicula auditus, and Eustachian tubes opening into the fauces by distinct orifices. Such are most of the genera of frogs and toads,—for example, Rana, Bufo, Alytes, &c.

3. Frogs with cartilaginous membrana tympani, a tympanic cavity wholly bounded by bony parietes, two ossicula auditus, and Eustachian tubes opening together in the middle of the palate by a single orifice. This form exists only in the genera Pipa and Dactylethra. Of the three ossicula present in the former division of the Batrachia, the first

* See Windischmann, De Penitiori Auris in Amphibiis Structurâ; Bonnæ, 1831.

has here become metamorphosed into the cartilaginous membrana tympani; the second is a very long, bent, styliform body, to which the third is a scarcely perceptible lamella-like appendage closing the fenestra vestibuli.*

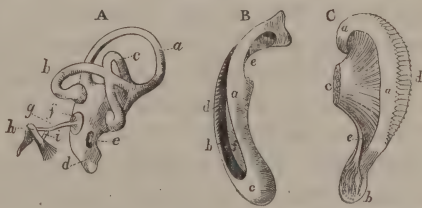
The reptiles have both the fenestra vestibuli and the fenestra cochleæ. The cochlea, except in the Chelonia (turtles and tortoises), has the same form as in birds.

The reptiles without tympanic cavity are the serpents, and also Chirotæ, Lepidosternon, and Amphibæna. The only one of the ossicula existing here is the stapes, which is prolonged into a style-like body of more or less considerable length (the columella). This, together with the fenestra, is covered by the muscles and skin.

The reptiles with tympanum and Eustachian tube are, the Chelonia, Crocodilida, and Lacertæ, as well as the Saurians devoid of extremities, which have eye-lids, — namely, Bipes, Pseudopus, Ophisaurus, Anguis, and Acontias. The columella exists here as in the former group, and is connected with the membrana tympani by means of a fibro-cartilaginous mass.† In most of these reptiles provided with a tympanum the membrana tympani is visible externally; but in some of the last-named genera it is covered by the skin.

In birds the organ of hearing (fig. 127, A) has in most respects — namely in the structure of the tympanum, columella, and cochlea, — the same confirmation as in the Crocodilida and Lacertæ. The tympanum communicates with cavities in the cranial bones, which thus become filled with air, and increase the extent of surface, tending by resonance to render sounds more intense. The cochlea (fig. 127, B, C,) is not convoluted, but is a nearly straight canal, closed at its extremity, and divided by a very delicate membranous septum into two passages, the scala tympani, and the scala vestibuli. The septum is extended in a cartilaginous frame, which towards the blind extremity of the cochlea arches over in a pouch-like

Fig. 127. ‡



* See J Müller, in Tiedemann's Zeitschrift, iv. 2; and Müller's Archiv. 1836, lxvii.

† J Müller, in Tiedemann's Zeitschrift, iv. 2.

‡ [Organ of hearing in birds. — A. General form of the organ of hearing in *Corvus corax*, magnified (after Breschet). *a*. Anterior semicircular canal; *b*. external canal; *c*. posterior canal (the osseous canals only coalesce as here represented; the membranous canals within are distinct); *d*. the cochlea; *e*. fenestra cochleæ; *f*. fenestra vestibuli closed by the base of the stapes, *g*. *h*. malleus; *i*. small bone analogous to the incus. — B. Cartilage of the cochlea of the owl (after Huschke). *a*, *b*. The opposite portions of the

form, bearing the same relation to the septum that the upper leather of a slipper bears to the sole (fig. 127, B). The arch of this pouch, or lagena (Huschke,) is continued along the whole length of the cochlea by a vascular membrane thrown into transverse plicæ (fig. 127, C). These folds are what Treviranus first described as isolated lamellæ, analogous to the keys of a pianoforte. The sacculus ovalis vestibuli, or sinus communis canalium semicircularium, and the flask or pouch-like part of the cochlea, contain a crystalline powder composed of carbonate of lime.*

Mammalia generally have an organ of hearing, which is not essentially different from that of man, and the varieties of form which it presents are not, for the most part, of such physiological importance as to render it necessary for us to describe them. The cochlea is always convoluted, and possesses a spiral lamella, formed partly of bone and partly of membrane, running round the central modiolus: the cochlea of the *Ornithorhynchus*, and that of the *Echidna*, are the only exceptions, resembling in all respects the same part in birds. The bony tympanum has in many *Mammalia* the form of a large osseous pouch, generally resulting from a developement of the os tympanicum. In many animals the cavity of the tympanum extends into other contiguous bones. In some there is also a second superior tympanum, formed by the pouch-like expansion of the os petrosum upwards and backwards; such a cavity exists, for example, in the genera *Pedetes*, *Dipus*, and *Macroscelides*. These are all means for increasing the extent of the cavities for resonance. The *Cetacea* and the *Ornithorhynchus* have no external ear; the Eustachian tube in the *Delphinus* family opens into the nasal cavity; and the external auditory passage of animals living entirely in the water is extremely narrow.

The ultimate distribution of the auditory nerve in the cochlea, and the observations of Treviranus and Gottsche relative to that subject, have been referred to at page 605. Just as the nervous fibres are spread out in the cochlea upon the lamina spiralis for the purpose of being in contact on both sides with the fluid of the labyrinth, so also in the ampullæ of the semicircular canals they are, as Steifensands has shown, † expanded upon a process, which, however, is not carried entirely through the ampulla, but merely projects into it. Into the ampulla of each semi-

cartilage; *c.* flask or lagena of the cartilage; *d.* dentations of the principal branch of the cartilage; *e.* situation of the fenestra ovalis; *f.* fine membrane closing the cleft between the branches of the cartilage.—C. Soft parts of the cochlea of *Strix stridula* (after Breschet). *a.* Cartilage; *b.* lagena, containing a calcareous pulp; *c.* cochlear nerve, sending through the cartilage numerous filaments, which issue by the dentations of its border, and contribute to form the plicæ of the arched membrane, *d.*; *e.* branch of the nerve going to the lagena.]

* See Windischmann, loc. cit.; Huschke, in Müller's Archiv. 1835, 335; Breschet, Ann. d. Sc. Nat. 1836; Müller's Arch. 1837, lxiv.

† Müller's Archiv. 1835, 171.

circular canal in Mammalia a transverse rounded body projects like an imperfect septum at the part corresponding to the expansion of the nerve on the ampulla.* In birds, a process with a rounded extremity projects upwards from this septum, and another similar one downwards; so that the whole resembles a cross, of which the transverse branches are fixed to the walls of the ampulla, the perpendicular branches free. In the tortoise, the rounded septum of the posterior ampulla has merely one boss-like prominence (umbo) in its centre. The septum of the anterior ampulla is placed transversely upon the parietes of the cavity, and has not this prominence: in the external ampulla only half of the septum exists. In crocodiles and lizards the external ampulla resembles that of the tortoise; the others have the septum of the cruciate form. In fishes the septum is a rounded transverse fold.

All the acoustic contrivances of the organ of hearing are means for conducting the sound, just as the optical apparatus of the eye are media for conducting the light. Since all matter is capable of propagating sonorous vibrations, the simplest conditions must be sufficient for mere hearing, for all substances surrounding the auditory nerve would communicate sound to it. In the eye a certain construction was required for directing the rays or undulations of light in such a manner that they should fall upon the optic nerve with the same relative disposition as that with which they issued from the object. In the sense of hearing this is not requisite. Sonorous vibrations having the most various direction and the most unequal rate of succession, are transmitted by all media without modification, however manifold their decussions; and, wherever these vibrations or undulations fall upon the organ of hearing and the auditory nerves, they must cause the sensation of corresponding sounds. The whole developement of the organ of hearing, therefore, can have for its object merely the rendering more perfect the propagation of the sonorous vibrations and their multiplication by resonance; and, in fact, all the acoustic apparatus of the organ may be shown to have reference to these two principles.

For the mere perception of sounds, therefore, neither *membrana tympani*, *ossicula*, *cochlea*, *semicircular canals*, nor even the vestibule and fluid of the labyrinth, are essential. Hence all these parts may be absent.

The organ of hearing of invertebrate animals is reduced to a mere *sacculus*; and in some Invertebrata even this is wanting, and the mere nerve, with the specific endowments, appears here to be all that is required. Every substance is capable of propagating undulations; and the body of an animal, and the parts immediately surrounding the audi-

* [Steifensands' figures of this structure in man will be found copied in Mr. Wharton Jones's art. Organ of Hearing, in the Cyclopæd. of Anat. and Physiology, which may be consulted with reference to the structure of the human ear generally.]

tory nerve, will receive them in the same order in which the conducting medium propagates them: it cannot, therefore, be maintained even that the distinction of the pitch and relative intensity of the sounds requires special apparatus. The distinctness and absolute intensity of the sounds will, however, increase with the acoustic developement of the organ.

The use and mode of action of this apparatus will be best learnt by following them from their simplest forms through the different stages of their developement in which new parts are added. We thus ascertain what parts are independent of others, and what parts necessarily co-exist with each other.

2. Of the propagation of sound to the labyrinth in aquatic animals.

In animals living in the atmosphere, and hearing through its medium, the sonorous vibrations of the air are communicated first to the solid parts of the body of the animal and of the organ of hearing, and by them to the fluid of the labyrinth. The intensity with which sounds are heard by these animals must, therefore, depend on the degree in which the solid parts of the organ of hearing are susceptible of the vibrations communicated to them by the air, and on the degree of diminution which the excursions of the vibrating particles suffer in the passage of the vibrations from the air to the solid external parts of the organ of hearing, and further on the degree of facility with which vibrations can be communicated by these external parts of the auditory apparatus to the fluid of the labyrinth. The whole external part of the auditory apparatus is calculated, as we shall see, to render less difficult the communication of sonorous vibrations of the air to solid bodies.

In animals living in the water, and hearing sound through its intervention, the problem is a very different one. The medium by which the sonorous vibrations are conducted to the animal is here the water: it communicates them to the solid parts of the body of the animal, whence they are in turn transmitted to the fluid of the labyrinth. The intensity with which the sound is heard depends, in this case, on the degree in which the solid parts of the organ of hearing, through which the sonorous undulations must first be transmitted, are capable of receiving the undulatory movement from the surrounding water, and of imparting it again to the fluid of the labyrinth, and on the degree in which the excursions of the vibrating particles are diminished in the transition of the vibrations from the one medium to the other. We shall see here also that the whole external portion of the auditory apparatus is calculated to facilitate this transition of the vibrations.

Undulations being communicated from the air to solid bodies, and from water to solid bodies, with very unequal intensity, and their transition from the one medium to the other being facilitated by very differ-

ent means in the two cases, it has been necessary for nature to employ very different apparatus in forming the external portion of the organ of hearing in animals hearing sounds through the medium of the air, and in those to which water is the conducting medium; while the internal parts of this organ have a much more uniform construction.

The problem to be solved in the case of aquatic animals is in general simpler than that which presents itself in reference to the hearing of animals living in the air. In the former the sound is propagated to the auditory nerve by three media in succession, of which two, however, are of the same nature: 1, the water in which the animal lives; 2, the solid parts of the animal's body, and of the organ of hearing; and 3, the fluid of the labyrinth. In animals living in the atmosphere the sonorous vibrations are communicated by three media in succession, which are all different: namely, the air; the solid parts of the body of the animal, and of the auditory apparatus; and the fluid of the labyrinth. For this, and no other reason, is the organ of hearing generally more complicated in the latter animals. The organ of hearing of aquatic animals, as fishes, being ordinarily wholly enclosed by solid structures, the first question which presents itself respects the transition of sonorous undulations from water to solid bodies, and from these to water (the fluid of the labyrinth). We know that, in the transition of sonorous undulations from air to solid bodies, a considerable diminution of the excursions or impulses of the vibrating particles, takes place; while the undulations are communicated from air to air, or from one solid body to another, without any diminution of their intensity. The full sound produced by a solid body vibrating, such as a string without a sounding-board, is only heard when it is conducted to the solid parts of the ear by means of a solid medium,—for instance, by a rod interposed between the bridge over which the string is stretched, and the external ear, the meatus of which is filled with a solid substance. If merely the air intervenes between the solid body which is the source of the sonorous vibrations and the ear, the sound heard is feeble; for the communication of the vibrations of a solid body to the air is attended with diminution of the excursions of the vibrating particles, or of the impulse. On the other hand, the sonorous vibrations of a body of air, such as that of a wind instrument, are propagated and communicated to the ear with their full intensity by the atmosphere; but are imparted with difficulty, and only with a diminution of their force, to solid bodies. Hence the sound of a pipe is not heard better by placing a rod reaching to the vicinity of the sonorous column of air in apposition with the ear plugged with a solid substance. Does the same difficulty prevail in the transition of undulations from water to solid bodies? Is a diminution of their intensity here also the result?

This subject has not hitherto been at all investigated. The imperfect

state of the acoustics of the auditory apparatus, which can indeed be scarcely said to have existed hitherto, led me to institute a series of experiments relative to this point, the results of which I shall now state.

I. *Sonorous vibrations excited in water are imparted with considerable intensity to solid bodies.*—This is shown by the following experiment:—A basin of glass, porcelain, or wood, is filled to the brim with water, on the surface of which a shallow vessel is made to float without touching the basin. A sound is produced in the floating vessel by dropping some solid body into it. If the ears are firmly stopped by means of plugs of twisted paper, of which the end that is inserted into the auditory passage has been previously chewed, while the other end projects from the ear, a sound produced by a solid body is heard through the medium of the air very indistinctly; but by the intervention of a rod of wood, or, what is better, a glass tube which is held in contact with both the sounding body and the plug in the ear, with very great distinctness and loudness. If, now, the glass rod still held in contact with the plug in the ear be immersed in the water of the basin while a body is dropped into the vessel floating on its surface, a loud and clear sound, such as a blow applied to that vessel always produces, is heard; and the sound thus heard is much louder than when transmitted to the ear through the medium of the atmosphere only. In this case, the sonorous vibrations are communicated from the floating cup or solid body to the water, and from the water again to the glass rod, and thus to the ear. Two things are here proved, namely, that solid bodies communicate their sonorous vibrations with great intensity to water, and, more than this, that water imparts them again very readily to solid bodies,—for instance, to the rod which conducts the sound to the ear. The result of the experiment is much the same, whether the rod be held in the water, or in contact with the walls of the basin containing it. The sonorous undulations communicated to the water are transmitted by it to the rod either directly or through the intervention of a second solid body. The sound heard may indeed be somewhat louder in the latter case, from the resonant action of the basin coming into play.

II. *Sonorous vibrations of solid bodies are communicated with greater intensity to other solid bodies brought into contact with them, than to water, but with much greater intensity to water than to atmospheric air.*—This may be readily shown by the foregoing experiment. The sound produced by the body falling into the floating vessel is heard with greatest loudness when the rod held in contact with the plug in the ear is lightly applied by its other extremity to the floating vessel itself. The sound is much fainter when the rod is immersed in the surrounding fluid, but it is much more feeble still when transmitted by the air alone to the plugs in the auditory passages.

III. *Sonorous vibrations are communicated from air to water with great difficulty, with very much greater difficulty than they are propagated from one part of the air to another ; but their transition from air to water is much facilitated by the intervention of a membrane extended between them.*

—That sounds produced in the air are heard in the water is a fact long known ; but a new fact which I have observed, namely,—that a membrane extended between water and air, which are in contact with its two surfaces respectively, facilitates in an extraordinary degree the communication of sonorous vibrations from the air to the water,—appears to me to be of great interest. If, while my ears are plugged, I cause a metal or wooden mouth- or flute-pipe one foot in length, and destitute of side openings, to be sounded, the lower end of the pipe being at the time immersed in water, the sound which I hear by means of the rod, also immersed in the water and in contact with the plug of one ear, is very feeble even when the pipe is held perpendicularly in the water, so that the undulations of the air strike upon the fluid in that direction. If however, a piece of thin membrane, as pig's bladder, is tied over the lower opening of the pipe, not very tensely, the sound which reaches my ear by the same means as before, when the pipe is blown, is very loud ; particularly if the rod which conducts the sound to the ear is held in the direction of the undulations, that is, in the line of the pipe. The sounds thus heard are very sonorous. The lowest or fundamental note, or one of the middle notes of the pipe, is best suited for the experiment. The rod used to conduct the sound to the ear is a rod of wood, or, still better, a glass tube six or eight lines in diameter, which is held at right angles in the line of direction of the sonorous vibrations of the water. If the rod, while in contact with the ear by its upper extremity, be moved to and fro in the water, the sound of the pipe will be found to increase in intensity (swells) each time that the rod passes in front of the membrane covering the lower mouth of the pipe. This contrivance is indispensable in all the subsequent experiments on hearing in the water, and on the acoustic properties of the different parts of the organ of hearing ; it has been of the greatest use in my researches, and without it I should have arrived at no results. The higher or more acute notes of pipes are heard with but little or no increase of intensity by this means. The experiment proves, at the same time, that the undulations in water, as in air, though in general circular or spherical in form, are nevertheless more intense in the direction corresponding to that of the original impulse.

IV. *Sonorous vibrations are not only imparted from water to solid bodies bounded by definite surfaces which are in contact with the water, but are also returned with increased intensity by these bodies to the water, so that the sound is heard loudly in the vicinity of those bodies in situations where, if it had its origin in the conducting power of the water alone, it*

would be faint.—In the experiment described in the preceding paragraph, the sound of the pipe, closed at its lower extremity by a membrane, was heard by means of the conducting-rod with great distinctness when water merely was interposed between the end of the pipe and the conductor, this conductor being placed in the line of the direction of the pipe. The sound is also heard with equal, or nearly equal intensity, when a thin lamina of wood is placed between the rod and the pipe; in which case the sonorous undulations have to pass from the water through this septum, and then through water again before they reach the conductor. But not merely is this the case at the part corresponding to the line of direction of the pipe; the sound is also loud in the vicinity of all parts of the surface of the wooden septum, even at a considerable distance from that line, and where it is heard faintly only when the wooden septum is removed. At all parts of this plate of wood the sound is heard louder than elsewhere in the water contained in the basin. If the basin itself be of wood, increased intensity of the sound can be perceived when the conducting rod is brought near its internal surface.

V. *Sonorous undulations propagated through water are partially reflected by the surfaces of solid bodies.*—This fact, which is of assistance in explaining the acoustics of the labyrinth of the ear, may be verified by means of the simple apparatus already frequently described. The ears being plugged as before, the pipe closed at its lower extremity by membrane is immersed in the water of a large basin; a glass cylinder, six inches in length, closed below and filled with water, is also immersed in the water of the basin, and held there by an assistant with both hands in such a manner that it does not touch the basin at any part. The end of the pipe being now introduced into the mouth of the cylinder, and its fundamental note elicited by a feeble blast, while the conductor is held near the mouth of the cylinder, but without coming into contact with it or the pipe, as loud a sound is heard as when the conducting-rod is held opposite the end of the pipe. This intensity of the sound is the result of reflection by the internal surface of the cylinder, and not merely of the resonance of its walls; for the intensity of the sound heard, as above described, is not diminished though the resonant power of the walls of the cylinder be lessened as much as possible by covering its internal surface with a layer of tallow, and by damping the vibrations of its walls externally by embracing it with both hands. Moreover, the sound heard by placing the rod in the water on the exterior of the cylinder is much fainter.

VI. *Thin membranes conduct sound in water without any loss of its intensity, whether they be tense or lax.*—A membrane interposed in the water between the end of the pipe and conducting-rod, which was held in the line of the pipe, caused not the slightest difference in the in-

tensity of the sound; which was loud in this situation, namely, opposite the end of the pipe, but feeble in all other parts. The membranous septum first used was tense, being formed by stretching a piece of pig's bladder over a large ring; but lax membranes, merely suspended in the water, afforded the same result. Even when several, namely, from four to eight layers of the bladder, which had been dried and again soaked, were laid one upon another, and pressed together so as to expel the air, and the septum, thus formed, interposed between the end of the pipe and the conducting-rod, some increased intensity of sound could still be remarked as the rod came opposite the end of the pipe, that is, in the direction of the impulses of the column of air in it. An addition of several thicknesses of the membrane entirely prevented this being perceived. A portion of human skin, and a piece of the wall of a pregnant uterus three lines in thickness, had the same effect; and the sound, as heard behind the screen thus formed, was not louder than in any other part of the water out of the direction of the strongest undulations.

VII. *The paragraphs III. IV. and VI. afford an explanation of the process by which the sound is conducted to the ear in aquatic animals not breathing atmospheric air.*—When we plug our ears very tightly, and use a rod of wood as a conductor of the sonorous vibrations from the water, we place ourselves entirely in the condition of the fish with respect to the hearing of sounds. Immersion of the head in the water is not necessary, nor is it calculated to allow of an undisturbed observation of the result. The solid conducting-rod forms a prolongation of the solid parts of our body, and brings them into immediate communication with the sonorous undulations of the water, as in the fish. The simple or compound labyrinth of aquatic animals is either wholly enclosed in the bone or cartilage of the cranium, as in the cyclostomatous and osseous fishes and the Sepiæ; or, its cavity being prolonged to the surface of the body, it is there brought into communication with the conducting medium by means of a membrane, besides receiving the vibrations through the medium of the solids of its body, which is the case in the plagiostomatous fishes and in the Crustacea, where the auditory sac is covered at one part merely by a membrane. The cranial bones are also capable of resonance, that is to say, the vibrations communicated to them are increased by reflection within them by their surfaces; and these reflected vibrations, as well as those directly communicated from without, are propagated to the labyrinth. This is illustrated by the facts stated in paragraph IV. In the plagiostomatous fishes (sharks and rays), which have a soft cartilaginous skeleton, this increase of the sound by resonance in the walls of the cranium may possibly be less considerable than in the osseous fishes; and it is on this account, probably, that the prolongation of the labyrinth to the surface of the body in the former was necessary. In the cyclostomatous cartilagi-

nous fishes (as the myxine and lamprey), the auditory sac belongs wholly to the solid parts of the skeleton, and in them it is also covered by muscles which must tend to deaden the sonorous vibrations propagated to it.

VIII. *When sonorous vibrations are communicated from water to air enclosed in membranes or solid bodies, a considerable increase of the intensity of the sound is produced by the resonance of the air thus circumscribed.*—The pipe, closed by membrane at its lower extremity and immersed in water, was sounded by an assistant, while I conducted the sonorous vibrations to my ear (stopped as before) by means of a conducting-rod. The air-bladder of a fish (*Cyprinus Erythrophthalmus*; German Plötze) was now held in the water, between the end of the pipe and the conductor, but so as to be in contact with neither; when, the pipe being sounded again, the sound heard was much louder than before, though the distance of the conducting-rod from the end of the pipe remained the same. This experiment proved, first, that with the intervention of membranes sound is transmitted very readily, and without any loss of intensity, from water to air, and again from air to water; and, secondly, that if the air be enclosed in a membrane surrounded on all sides by water, the resonance of the body of air thus isolated, that is, the partial reflection of the sonorous undulations at the surfaces of the air, and consequent production of stronger undulations, gives rise to a considerable increased intensity of the sound.

IX. *A body of air enclosed in a membrane, and surrounded by water, also increases the intensity of the sound by resonance when the sonorous undulations are communicated to it by a solid body.*—The air-bladder of the same fish was fixed in the cleft of a rod of wood; this rod was held firmly in contact with the walls of a basin filled with water, into which the air-bladder projected; a vibrating tuning-fork was then brought into contact with the edge of the basin, while I applied a conducting rod immersed in the water to one of my ears, which were plugged as in the other experiments. The result was, that the sound heard was very much louder when the rod was brought near the air-bladder, than when it was at any other part of the water equally distant from the source of the sound; it was as loud, indeed, near the air-bladder as it was near the sides of the basin.

According to the laws of the propagation of sound in the atmosphere, this resonance of a body of air should be greater in proportion to the degree of its condensation, since the intensity of sonorous undulations in a gaseous fluid increases in direct ratio with its density, and the sound of a bell in the receiver of an air-pump becomes fainter and fainter as the air is rarefied, until at length it ceases to be heard. In direct experiments, however, condensation of the air in the air-bladder of a fish seems to produce little difference in the degree of resonance. I per-

formed the experiment as before, with the difference only of fixing the air-bladder to the pipe of an air-tight syringe, by which the air in the bladder could be much condensed. The air-bladder, being invested by an external fibrous or tendinous coat, yields scarcely at all to the distending force.

X. *From the foregoing observations we may conclude that the air-bladder of fishes, in addition to other uses, serves the purpose of increasing by resonance the intensity of the sonorous undulations communicated from the water to the body of the fish.*—The sonorous vibrations of the water are communicated to the air of the air-bladder partly through the soft parts of the fish's body, and partly through the medium of the bones, namely, the vertebræ, beneath which it lies; and it becomes the source of sonorous undulations, increased in intensity by resonance, which are in turn imparted from it to the surrounding parts, especially to the bones. It cannot, therefore, be denied that the air-bladder of fishes, even when it is not connected with the auditory apparatus, must contribute in some degree to render the impression of sound on the organ of hearing stronger; but where there exists a connexion of the air-bladder with the labyrinth, either through the medium of a chain of small auditory bones, or by a prolongation of the air-bladder itself, this viscus must have a most intimate relation with the organ of hearing, acting as the multiplicator, condensor, and conductor of the sonorous undulations imparted by the water to the whole body of the fish. In the genus *Cobitis* this seems to be the chief function of the air-bladder, which is very small,—lies, in greater part surrounded by bone, in a pouch-like excavation of the second vertebra,—and is anteriorly brought into connexion with the labyrinth by the small auditory bones.

The conducting and resonant power of the air in the air-bladder being greater in proportion to its density, the influence of this organ on the perception of sounds will, of course, be greater in deep waters, where the pressure upon it is considerably increased.*

In the Amphibia which live in water, as the Proteidea, the Amphiuma, Menopoma, and Bombinator families, the sonorous undulations are conducted to the labyrinth, not merely through the bones of the head, but also through the medium of a fenestra; which is not, however, merely closed by the skin as in plagiostomatous fishes (sharks and rays), but has a moveable operculum, the lamina of the stapes, which is connected to the margins of the opening by membrane. This fenestra of the labyrinth is, like the bones of the head generally, covered with muscles and skin. The degree in which such a structure will assist hearing in the water may be ascertained by experiment with

* J. Müller, *Physiologie des Gesichtsinnes*, 1826, p. 441.—Compare Carus, in the Report of the Proceedings of the Meeting of Naturalists (*Bericht über die Versammlung der Naturforscher*) in Jena; Weimar, 1837.

a similar artificial contrivance. Its principal use is, however, for hearing in the air, not in the water, as will be shown at a future page; for hearing in the water this structure of the fenestra would not have been required. The Amphibia in which it exists live both in the air and in the water.

3. *Of the propagation of sound to the labyrinth in animals living in the air.*

The propagation of the sonorous vibrations from the surface of the body to the fluid of the labyrinth, requires in an animal living in the air a much more complicated apparatus than in an aquatic animal, in consequence of the transition of the vibrations from air to the solid parts which surround the organ of hearing and the fluid of the labyrinth being attended with much greater difficulty than the transition of the vibrations from water to solid bodies. Accordingly, in most animals living in the air, the labyrinth has two fenestræ, of which one is closed by a membrane, the other by a solid operculum. Most of these animals have also a tympanum and Eustachian tube, and a double means of conducting the sound from the exterior to the labyrinth,—namely, a chain of solid bodies, the ossicula auditus, interposed between the membrana tympani and the fenestra ovalis of the labyrinth; and the air of the tympanum, which conducts the vibrations from the membrana tympani to the membrane of the fenestra rotunda. The dispute which has occupied physiological writers, as to which of these is the true conducting medium of the sound, has no scientific grounds. The air, membranes and small bones of the ear, are all capable of conducting sonorous vibrations, and they do respectively what their physical properties adapt them for. The propagation of the sound in two different ways simultaneously must necessarily strengthen its impression. The laws by which the propagation of sound from the exterior to the labyrinth of animals living in the air are regulated, have not hitherto been determined. We shall, therefore, investigate the subject as fully as we have done that of the process of hearing in aquatic animals.

To learn the acoustic value of each part of the apparatus, it is requisite to study them in the order of their progressive developement.

The propagation of sound to the fluid of the labyrinth in animals destitute of tympanum is seldom left to the conducting power of the cranial bones alone. Sonorous vibrations are imparted too imperfectly from air to solid bodies, for the propagation of sound to the internal ear to be adequately effected by that means. In nearly all animals living in the air, even in those which have no tympanum, the labyrinth has an opening, or fenestra, towards the exterior, which, when the tympanum is absent,

is covered by the skin and muscles. In the genera *Rhinophis* and *Typhlops* only did I find both fenestra and ossicula auditus wanting.

I. *Sonorous undulations, in passing from air directly into water, suffer a considerable diminution of their strength; while, on the contrary, if a tense membrane exists between the air and the water, the sonorous undulations are communicated from the former to the latter medium with very great intensity.*—This is the fundamental fact from which we start. The proof of it is contained in the experiment already described in paragraph III, page 1241. We have in this fact at once an explanation of the use of the fenestra rotunda, and of the membrane closing it. They are the means of communicating in full intensity the vibrations of the air to the fluid of the labyrinth, whether the tympanum exist or not. The thin membrane of the fenestra is in serpents not immediately in contact with the atmosphere, but is covered with skin and muscles: but these coverings do not essentially impede the transmission of sound; for, in the experiment just referred to, I found that, when the mouth of the pipe was covered with several layers of the pig's bladder, the fundamental note of the pipe, being sounded, was heard much more distinctly by means of the conducting-rod placed in the water, than when the mouth of the pipe was closed by a solid plug. This peculiar property of membranes is the result, not of their tenuity alone, as will be readily conceived, but of the elasticity and capability of displacement of their particles. In passing from the air into a solid body, sonorous vibrations are at once rendered feeble, whether the solid body itself be thick or thin; for the impediment to the propagation of the vibrations exists at their very transition from the one medium to the other. A membrane cannot, therefore, with respect to its influence in communicating sound from air to water, be regarded merely in the light of a very thin body. It is owing to the extensile property of membrane that sonorous undulations are so readily communicated to it from air, as though it were itself air; and that it so readily imparts them again to water, as though it were water.

It is, moreover, not necessary that the membrane be impregnated with moisture; the membrane covering the end of the pipe may be dry, and yet the sound transmitted by it, before it has become softened by the water, will be loud. This fact finds its application in the membrane of the fenestra rotunda in animals provided with a tympanum.

II. *The sonorous vibrations are also communicated without any perceptible loss of intensity from the air to the water, when to the membrane forming the medium of communication there is attached a short solid body, which occupies the greater part of its surface, and is alone in contact with the water.*—This fact elucidates the action of the fenestra ovalis, and of the moveable plate of the stapes which occupies it in animals living in the air, but destitute of tympanum and membrana tympani. To the mem-

brane stretched loosely over the end of the pipe I glued a circular piece of cork half an inch in length, and so broad as to cover the membrane to within a line of its edge. The pipe being now immersed in water, and its fundamental note sounded, I heard by means of the conducting-rod held in the water in the line of the pipe, (my ears being closed by plugs,) a sound which was nearly as loud as when the end of the pipe was closed by the membrane alone. The difference was immediately perceptible if the conductor was moved out of the line of the pipe; the sound heard became then much fainter. If, on the contrary, the lower end of the pipe was completely closed by a plug, no perceptible increase in the intensity of the sound could be perceived when the conducting-rod was brought opposite the mouth of the pipe. Whence it results that the same solid body, when separated from the pipe, and rendered mobile by a narrow portion of membrane left free around it, permits a transmission of sound with considerable intensity, but when firmly fixed in the mouth of the pipe, becomes a direct impediment to the passage of sound.

These observations prove that both fenestræ—that closed by membrane only, and the other with which the moveable stapes is connected—transmit very freely the sonorous vibrations from the air to the fluid of the labyrinth.

Of the animals living in the air, and destitute of tympanum, the Bombinatores, the land Salamanders, and the Cæcilix have only the fenestra ovalis, or that closed by the osseous operculum. Serpents, on the contrary, have both fenestræ.

Propagation of sound by the membrana tympani and ossicula auditus.

III. A small solid body, fixed in an opening by means of a border of membrane, so as to be moveable, communicates sonorous vibrations, from air on one side, to water, or the fluid of the labyrinth, on the other side, much better than solid media not so constructed. But the propagation of sound to the fluid is rendered much more perfect if the solid conductor thus occupying the opening (fenestra of the labyrinth) is by its other end fixed to the middle of a tense membrane which has atmospheric air on both sides.

Vibrations of the air are communicated to solid bodies with difficulty, and with a considerable diminution of their intensity; but a membrane is readily thrown into motion by them. Savart has shown that membranes of small extent, as the membrana tympani itself, even when made tense, are so affected by sonorous vibrations excited in their vicinity as to cast off sand which is strewed over their surface. It may also be proved by direct experiment, that a tense membrane is a much better conductor of the undulations of air than any other solid bodies bounded by definite surfaces; and, what is equally essential, that the vibrations are also communicated very readily by a tense membrane to solid

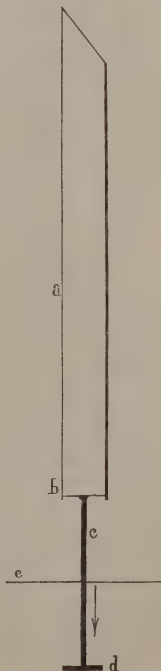
bodies in contact with them. The membrana tympani has not hitherto been considered under this point of view, namely, as the means of transmitting sound from the air to the chain of auditory bones. To elucidate this part of the subject, I performed the following experiments:—

A very thin membrane (paper) extended over the mouth of a cup, or similar vessel, is thrown into such vibrations when a vibrating tuning-fork is brought near it, that small bodies, such as seeds of *Lycopodium*, do not rest upon its surface. The vibrations of the air are, however, communicated also with great facility or intensity from the tense membrane to solid bodies which touch it at any point. If, for example, one end of a flat piece of wood be applied to the membrane of a drum while the other end is embraced by the hand, the vibrations or tremors are felt distinctly when the vibrating tuning-fork is held over the membrane without touching it; while the lamina of wood alone, isolated from the membrane, would, under otherwise similar conditions, propagate the vibrations of the air to the hand very feebly. In the following experiment the complication arising from the resonance of the air contained in the drum is avoided. A portion of very thin paper was stretched over a ring, and the ring held in one hand while the tuning-fork was approximated to the paper: the tremors were felt distinctly. The paper being removed, no vibrations could be perceived, even though the tuning-fork was brought very near to the ring.

Fig. 128.

The influence of the membrana tympani in causing the sound to be transmitted with great intensity by the chain of ossicula of the ear, is rendered manifest still more clearly by the following experiment:—

Over the extremity *b*, of a pipe one foot in length (*a*), was stretched a thin dry membrane (pig's bladder). To the middle of the membrane was glued a small piece of cork, which had attached to it a small rod of wood, *c*, while the other end of this rod was fixed in a disk of cork, *d*. The end of the rod was immersed in water (*e*), and the fundamental note, or one of the middle notes of the pipe, sounded. The ears being stopped, as in the experiments before described, and one end of a conducting-rod (a glass tube of the diameter of half an inch) applied to one ear, while the other end was moved about in the water, it was found that in a direction perpendicular to the surface of the lamina

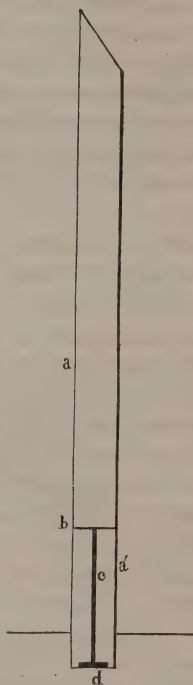


of cork, *d*, the sound was extremely loud, but in all other parts of the fluid much fainter.

In this experiment we could also satisfy ourselves that the strongest undulations were propagated in the longitudinal direction of the wooden rod, *c*. For when the glass conductor, still in the water, was brought near the rod, *c*, from the side, the sound heard, although loud, was not near so intense as in a direction perpendicular to the disk of the cork, *d*. If, in place of the membrane covering the end of the pipe, a plug of cork, inserted tightly, is substituted, the rest of the apparatus being the same, the sound is very slightly if at all louder in the direction of the rod,—that is to say, in a direction perpendicular to the plate of cork, *d*, than in other parts of the fluid.

Fig. 129.

The structure of the tympanum may be more exactly imitated on a large scale. Let *a* (fig. 129) be the pipe corresponding to the external meatus. A wooden tube, *a'*, which can be fixed to the end of the pipe, and which has a membrane, *b*, corresponding to the membrana tympani, stretched over that end which is contiguous to the pipe, represents the cavity of the tympanum: a rod, *c*, is fixed by its upper extremity to the membrane, *b*, and by its lower to a disk of cork, *d*, which is glued firmly to a membrane covering the lower end of the tube, *a'*, in such a manner that it is connected with the tube by a border of membrane a line in breadth; this disk of cork, *d*, and the rod, *c*, represent the stapes moveably attached in the fenestra ovalis. The lower end of this apparatus being immersed in water, and the pipe sounded, a conducting rod placed in the water opposite the end of the tube, or opposite the stapes, communicates to the stopped ear a sound as loud as was heard in the previous experiment.



The ossicula of the ear are the better conductors of the sonorous vibrations communicated to them, on account of being isolated by an atmosphere of air, and not continuous with the bones of the cranium; for every solid body thus isolated by a different medium propagates vibrations with more intensity through its own substance than it communicates them to the surrounding medium, which thus prevents a dispersion of the sound, just as the vibrations of the air in the tubes used for conducting the voice from one apartment to another are pre-

vented from being dispersed by the solid walls of the tube. The vibrations of the membrana tympani are transmitted, therefore, by the chain of ossicula to the fenestra ovalis and fluid of the labyrinth, their dispersion in the tympanum being prevented by the difficulty of the transition of vibrations from solid to gaseous bodies. The membrana tympani being a tense solid body bounded by free surfaces, the sonorous undulations will be partially reflected at its surfaces, so as to cause a meeting of undulations from opposite directions within it; it will therefore, by resonance, increase the intensity of the vibrations communicated to it, and the undulations thus rendered more intense will act in their turn upon the chain of auditory bones.

We have now to investigate the nature of the vibrations of the membrana tympani. Are they undulations of inflexion, like the transverse vibrations of strings and membranes? or are they undulations of condensation? An impulse communicated to a string or rod in the direction of its length gives rise merely to progressive waves of condensation, not to vibrations of the string or rod from side to side. But if a sufficiently thin body, as a string or membrane, receives an impulse in a direction perpendicular to its length or to its surface, undulations of inflexion are also produced. If the impulse affects one point only of the string or membrane, the flexion-waves are propagated from this point to the extreme limits of the body, and then reflected back again like undulations on the surface of water; if the body is displaced in its whole extent by the impulse, transverse vibrations of inflexion of the entire body are the result. The question to be decided then is, whether such vibrations of inflexion are produced in membranes propagating sonorous undulations, when they are affected by an impulse acting perpendicularly upon their surface; or whether undulations of condensation merely result? It is certain that sand and powder of *Lycopodium*, placed upon thin plates or membranes while these are the subject of sonorous undulations, are thrown into motion; Savart has indeed shown that this is the case with the membrana tympani itself when very loud sounds are produced in its vicinity. It must not, however, be thence inferred that the body upon which small particles are thrown into motion is necessarily affected with undulations of inflexion, for even undulations of condensation might excite motion in such light particles of matter by acting as an impulse upon them, and the particles of air affected with undulations of condensation communicated to them from the solid body may carry light substances with them. Even the nodal lines developed upon thin plates, to which sonorous vibrations are communicated, are no proof that the undulations of these plates are undulations of inflexion, for nodal points may be developed in a body whose vibrations consist of condensations and rarefactions of its particles, such as the column of air in musical pipes. Strings which reciprocate the

sound of another string vibrating in their close vicinity, give to the eye at least no evidence of being affected with transverse vibrations or undulations of inflexion; though this is, on the other hand, no proof that they are not the seat of such vibrations, since, when the excursions are not great, transverse vibrations are not visible. The drum, however, affords us distinct proof that membranes propagating sound may vibrate in this manner. If one membrane of a drum is struck so as to be thrown into vibration, the membrane of the opposite side is seen to vibrate transversely, and with excursions of considerable extent. The panes of a window also bend, and may even break, during the undulation of the air produced by the report of a cannon. It depends, therefore, entirely on the intensity of the impulse imparted to it by the sonorous vibration, whether a body extended in the form of a membrane, and capable of conducting sound, shall be thrown into undulations of inflexion or not. The possibility, therefore, of such undulations being excited in the *membrana tympani* cannot be denied; although, on account of its limited size, the extent of its oscillations must be very small, even when they are produced by the loudest sounds. Accurately speaking, the *membrana tympani* will become the seat of transverse oscillations whenever the space through which its particles move in the undulations excited by sonorous vibrations of the air exceeds the thickness of the whole membrane; and, when the impulses of the air have a certain degree of intensity, this must occur. The articulation and relative position of the small bones of the ear being such as to allow an approximation of the two extremities of the chain which they form, the oscillations of the *membrana tympani* are not impeded by them. Even where only one of the ossicula exists, as in birds and reptiles, its outer extremity, which is connected with the *membrana tympani*, is mobile. We may from these considerations infer that the articulation of the small bones of the ear has not a relation merely to the action of muscles upon them,—which, indeed, is sufficiently proved by reference to comparative anatomy, for they have moveable articulations in the frog as in man, though they have there no muscles attached to them.

On examining, however, more closely the conditions of the propagation of sonorous undulations in the atmosphere, we find that only the most intense sounds can possibly give rise to oscillations of the *membrana tympani* as a whole. If the extent of oscillation of the particles of a body emitting sound, or the intensity of an impulse, be so great that the rate of motion of the particles giving the impulse is equal to the velocity of sound in the air, the extent of oscillation of all the particles of air affected by the undulation will be equal to the extent of oscillation of the particles of the body communicating the impulse to the air, provided the air thus affected be confined in a tube. If the velocity of the particles communicating the impulse be only half as great as the

velocity of sound in air, the extent of oscillation of the particles of the air (in a tube) will be only half as great as the extent of oscillation of the particles communicating the impulse to them. All the particles of air in a tube will oscillate through the same space when the undulation reaches them.* Vibrations of the membrana tympani, as a whole, will therefore be most prone to occur when the sound of a body oscillating with great intensity is transmitted to the ear through a tube; but the propagation of sound through an unconfined body of air is attended with a progressive diminution of the intensity of the undulations, or of the extent through which the oscillating particles of air move. For while the length of the waves—that is, the distance from the commencement of one wave to the commencement of the next,—remains the same during the propagation of spherical undulations of constantly increasing extent from one point in the atmosphere, the extent of oscillation of the particles affected by these waves diminishes in the ratio of the squares of their distance from their centre or source.† If, for example, the extent of the oscillations of the particles of air in the immediate vicinity of a sounding body, or of a body communicating an impulse to it, were an inch, the extent of their oscillation at the distance of two feet would be a quarter of an inch, at the distance of three feet $\frac{1}{9}$ th, at four feet $\frac{1}{16}$ th, and at ten feet $\frac{1}{100}$ th of an inch, which is less than the thickness of the membrana tympani.

In calculating the effect of sonorous undulations on the membrana tympani, we must, moreover, take into account the difference in the velocity with which sound is propagated by it and by the air, and also the resistance offered by its attachments, which, even though the extent of the oscillation of the particles of air striking it exceeded the thickness of membrane, would cause the extent of its movement to be much less considerable.

The oscillations of the membrana tympani as a whole, produced by very intense sounds, will, if the undulations of the air fall upon the membrane in a perpendicular direction, occupy its whole extent at once; but if the undulations of the air fall upon it obliquely, so as to strike one part of it before the rest, the movement of the membrane will commence at this point, and will thence extend to the other parts, like the oscillation which is excited near one extremity of a cord or musical string, or at one limited part of the membrane of a drum. These oscillations, being reflected at the borders of the membrane, will traverse it to and fro. In consequence of the oblique position of the membrana tympani, this must always occur when the sonorous undulations enter the ear in the direction of the meatus auditorius externus,—that is, in a direction parallel with its axis. When the sonorous undulations enter the meatus in any other direction, they will be reflected back-

* Weber, *Wellenlehre*, p. 503. † Ibid. p. 504.

wards and forwards by the walls of the passage; and it will depend on the angles at which they are reflected, in what manner, and at what point, they shall first strike upon the membrana tympani.

The propagation of the undulations of condensation and rarefaction, in which the smaller particles merely of the membrane move, is also modified in the same way by the mode in which undulations of the air strike it. The undulations of the air either strike every part of its surface simultaneously, or one point of it before the rest: in the latter case, the undulations communicated to the membrane are propagated in it in a determinate direction as far as its border, and then reflected back, so as to give rise to the crossing of undulations in the membrane. All sonorous undulations communicated to the membrana tympani by the solid parts of the head,—such as the cartilage of the outer ear, the walls of the external meatus, and the cranial bones,—are, of course, undulations of condensation and rarefaction of the particles. The undulations thus communicated to it are condensed and rendered more intense by the membrane.

If the undulation of the air be compound, so that during its progressive movement the most condensed part changes its relative position in the entire undulation, (in the same way that, while a string struck near one end vibrates transversely, the summit of its wave travels to and fro from one end to the other,) the membrana tympani will become the seat of undulations of the same character, and will give rise to the perception of a sound of the tone or timbre which that form of undulation is calculated to produce. If the undulations of the membrana tympani were in this case of the nature of transverse oscillations, the form of these oscillations would be, for example, similar to those described as being presented by a string struck near one extremity. If they were undulations of condensation and rarefaction of the particles of the membrane, they would have a direct progressive movement through the thickness of the membrane, with, at the same time, a lateral movement to and fro of the maximum of condensation and rarefaction in each wave. It will be readily conceived that such compound undulations are necessarily propagated unchanged through the chain of ossicula in the tympanum.

The necessity for the presence of air on the inner side of the membrana tympani,—in other words, the necessity for the existence of the tympanic cavity,—to enable the membrana tympani and ossicula auditus to fulfil the objects which we have described, is obvious. Without this provision, neither would the vibrations of the membrane be free, nor the chain of bones isolated, so as to propagate the sonorous undulations with concentration of their intensity. But while the oscillations of the membrana tympani are readily communicated to the air in the cavity of the tympanum, those of the solid ossicula will not be con-

ducted away by the air, but will be propagated to the labyrinth without being dispersed in the tympanum. Equally necessary is the communication of the air in the tympanum with the external air through the medium of the Eustachian tube for the maintenance of the equilibrium of pressure and temperature between them.

The propagation of sound through the ossicula of the tympanum to the labyrinth must be effected by undulations of condensation and rarefaction of their particles only, not by oscillations of the entire bones, even in cases where the entire membrana tympani oscillates; for, if the stapes were in its vibrations alternately more nearly approximated and removed from the labyrinth, the fluid of the latter cavity must necessarily be very compressible. The extent through which the individual particles affected by the undulations oscillate equal very minute fractions only of the length of the stapes.

The long process of the malleus, *b* (fig. 130), receives the undulations of the membrana tympani (*a, a*) and of the air in a direction nearly perpendicular to itself. The undulations maintain this direction through the whole chain of ossicula quite independently of its direction, and of that of the individual bones forming it. From the long process of the malleus the undulations are propagated to its head, which projects from it at an angle; thence into the incus (*c*), the long process of which has a direction parallel with the long process of the malleus. From the long process of the incus the undulations are communicated to the stapes (*d*), which is united to it at right angles. All these changes in the direction of the chain of bones have no influence on that of the impulse, which remains the same as it was in the meatus externus and long process of the malleus, so that the undulations are communicated by the stapes to the fenestra ovalis in a perpendicular direction. The proof of this statement is contained in M. Savart's experiments on the propagation of sound in solid plates united to each other at right angles.* The plate *b* (fig. 131) is so connected with the support to which the string *a* is attached, that, when the string is made to vibrate transversely, the same kind of vibrations are communicated to it. Another lamina, *c*, connected with the former at right angles, vibrates in the longitudinal direction, the vibrations communicated to it maintaining their original course. The lamina *d*, having a direction perpendicular to that of the former lamina *c*, again vibrates,

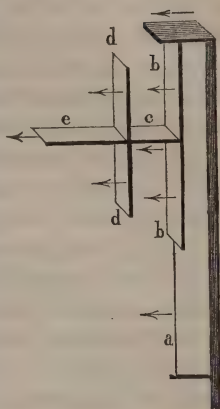
Fig. 130.



* Ann. de Chim. et de Phys. t. xxv. p. 12, 138, and 225.

transversely, and the plate *e* longitudinally. The direction of the vibrations in the different plates was shown by the direction in which the dust was thrown from their surface. It is indicated in the figure by arrows. The analogy between the vibrations of the plates in M. Savart's experiment, and that of the bones of the ear, is manifest. The string *a* in M. Savart's figure may be compared to the membrana tympani. The plate *b*, which is fixed to the support of the string, is analogous to the long process of the malleus, which, being the means of making tense the membrane, may also be regarded as its bridge or support. The plate *c* answers to the head of the malleus; the plate *d*, to the long process of the incus; and the plate *e*, to the stapes.

Fig. 131.



Tension of the membrana tympani.

IV. *A membrane of small extent propagates sound better in the lax condition than when made very tense.*

The inquiry respecting the capability of the membrana tympani to conduct sound better in its lax or in its tense condition, may be made to embrace membranes generally. We must, however, distinguish here between reciprocation of sonorous vibrations, resonance, and conducting power. The reciprocation of sounds is a phenomenon which bodies rendered elastic by tension are not capable of manifesting in their lax condition. A string made tense is capable of reciprocation, however, only under certain conditions; of resonance under all conditions. The sound excited by a vibrating tuning-fork is much louder when the fork is held near the tense membrane of a drum than when it is held in the vicinity of a perfectly lax membrane; but, in order that a body shall reciprocate a sound in its own proper fundamental note, it is necessary that its fundamental note should be in unison with the original sound, or that it should at least bear a simple relation to it; otherwise, it will merely render the original sound louder by resonance.

The degree of resonant action of a body, however, also depends, *cæteris paribus*, on the pitch of its fundamental note, and on the relation which it bears to the original sound.

If a vibrating tuning-fork be held over the mouth of tubes of paste-board of different lengths, the resonance of their column of air will be less marked in proportion as the fundamental note which it is calculated to give is more distant in the musical scale from the note

emitted by the tuning-fork: there will, therefore, be one length of tube in which the resonance will be loudest. If the length of the tube be such that the fundamental note of its column of air is in unison with the original sound, it will reciprocate that sound. The resonance of a column of air will, according to Mr. Wheatstone, be loud also when its length is a multiple of the column of air in unison with the tuning-fork, nodal points being in this case developed. A glass vessel may, by a greater or less quantity of water being poured into it, be tuned so as to increase the intensity of the sound of a tuning-fork in a great or a very slight degree. These principles being applied to strings and membranes, a membrane perfectly lax will not increase the intensity of a sound by resonance, or, at least, will do so in a much less degree than a tense membrane; but the resonance will, of course, not increase in intensity, *pari passu*, with the degree of tension of the membrane. On the contrary, it will be greatest when the tension of the body (supposing its mass to remain the same) is such that its fundamental note is in unison with the original sound.

A more particular application of these principles to membranes of so small extent as the membrana tympani is scarcely possible. It is of much more importance here to inquire whether increasing tension of the membrana tympani increases or diminishes the facility of transition of sonorous undulations from the air to it.

M. Savart was the first, and has hitherto been the only physiologist, who has endeavoured to elucidate this problem by experiment. He observed that the dry membrana tympani, on the approach of a body emitting a loud sound, rejected particles of sand strewn upon it more strongly when lax than when very tense; and inferred, therefore, that hearing is rendered less acute by increasing the tension of the membrana tympani.* M. Savart obtained a similar result when he produced increased tension of an extended membrane by means of a lever applied to it. Repeating M. Savart's experiment, with very thin paper extended over the mouth of a drinking-glass, I obtained the same result. The more forcible agitation of the grains of sand does not, however, justify our concluding with certainty that the sonorous undulations of the membrane are more intense. Muncke† remarks, that the agitation of the sand may arise from the greater extent (amplitudo) of the undulations, and not depend on their intensity; and that the pressure of the lever by which the tension is increased may give rise to the developement of a nodal line, by which the extent of the vibrating parts would be limited. Fechner, also, questions the correctness of Savart's conclusions. Under these circumstances, it appeared to me that direct experiments upon the relative capability of membranes of small ex-

* Ann. d. Chim. et Phys. t. xxvi. p. 25.

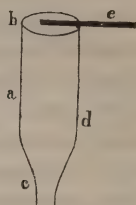
† Gehler's Physik. Wörterbuch, iv. 2, p. 1210; 3, p. 501.

tent, in the relaxed and in the tense conditions, to transmit sound, the ear itself being employed as the measure, would be of considerable interest.

A wooden tube, *a* (fig. 132), was employed, the diameter of whose lumen was eight lines, and length four inches, and which at one end diminished to a smaller neck, *c*, so that it could be inserted deeply and firmly into the external auditory passage. This smaller end was open; the other (*b*) was covered with a membrane which was not tightly stretched. Upon the membrane, a small rod, *e*, two lines broad, was glued, its extremity reaching a little further than the middle of the membrane, while the larger part of the rod projected far beyond the edge of the tube, to which it was firmly tied. Hence, when the outer end of the rod, *e*, was raised, the inner end was depressed, and the membrane consequently pressed inwards and made tense. The apparatus thus resembled, to a certain extent, the natural structure of the *membrana tympani*, the rod representing the *malleus*. The narrow end of the tube being now inserted into one ear, while the other was closely stopped with a plug of chewed paper, it was easy to compare the strength of the sound transmitted by it in different states of tension and relaxation. By the addition of a small opening in the side of the tube, at *d*, the influence of the Eustachian tube may be imitated, the air in the interior of the tube being thus enabled to maintain its equilibrium with the air without. But this produces no essential difference in the result; and it is better that the opening should not exist, since it would admit sonorous undulations to the ear, which had not passed through the membrane on the mouth of the tube. The result was in all my experiments the same. The sound was transmitted with much greater intensity through the lax membrane than through the membrane made tense by raising the outer extremity of the rod. A watch may be used as the source of the sound in these experiments. But every noise is heard louder when the membrane is lax; and its intensity diminishes in proportion as the tension of the membrane is increased.

The *membrana tympani* in one's own person may, however, be rendered tense so as to produce this influence on the intensity of sounds at will. In the dead subject, the *membrana tympani* may be rendered more tense in two ways besides by the retraction of the *malleus*; namely, by exhausting the air in the tympanum by sucking through the Eustachian tube, and by forcing more air into the tympanum through the same canal. In the first case, the *membrana tympani* is pressed inwards. In the second case, it is forced outwards; the long process of

Fig. 132.



the malleus, however, not being displaced by the pressure of the air within the tympanum, the centre of the membrane is prevented from changing its position, while the rest of it is protruded.

Both these modes of tension of the membrana tympani may be practised in the living body also, and in the experiment on our own persons, namely, by a strong and continued effort of expiration while the mouth and nostrils are closed, or by a strong and long-continued effort of inspiration under the same circumstances. In the first case, the compressed air is forced with a whizzing sound into the tympanum, and immediately hearing becomes indistinct. The same temporary imperfection of hearing is produced by rendering the membrana tympani tense, and convex towards the interior, by the effort of inspiration; a fact first noticed by Dr. Wollaston.* The imperfection of hearing, produced by the last-mentioned method, continues even after the mouth is opened, in consequence of the previous effort at inspiration having induced collapse of the walls of the Eustachian tubes, which prevents the restoration of equilibrium of pressure between the air within the tympanum and that without; hence we have the opportunity of observing that even our own voice is heard with less intensity when the tension of the membrana tympani is great. If I have produced increased tension of the membrane by forcing air through the Eustachian tube into the tympanum, the equilibrium of the air within and without the tympanum is usually restored, and hearing regained immediately upon the mouth or nostrils being opened; sometimes, though rarely, the natural condition is only gradually regained. On the contrary, when I have produced the tension of the membrana tympani by rarefying the air in the tympanum, the partial deafness usually lasts for some time, and during this period I feel very distinctly a sensation of tension in the membrane of the tympanum. In either case, if the imperfection of hearing and sensible tension of the membrana tympani do not cease spontaneously on the mouth being opened, I can remove them by a voluntary movement in the ear, which I shall presently show to be produced by a voluntary contraction of the tensor tympani muscle. The re-opening of the Eustachian tube, or the separation of its collapsed walls, is probably effected by the slight pressure of the air in the tympanum, when the tensor tympani acts so as to draw inwards the membrane. Persons who are not able to execute this voluntary movement of the tensor tympani muscle may still dispel the deafness by the contrary proceeding to that which produced it. If, for example, the imperfection of hearing had been induced by forcing outwards the membrana tympani, they should make a strong effort at inspiration while the mouth and nostrils are closed, and *vice versâ*.

If the pressure of the external air or atmosphere be very great, while,

* Philos. Transact. 1820.

on account of collapse of the walls of the Eustachian tubes, the air in the interior of the tympanum fails to exert an equal counter-pressure, the membrana tympani will of course be forced inwards, and imperfect deafness be produced. It is thus, in my opinion, that we must explain the singular observation of M. Colladon, that in the diving-bell both the voices of his companions and his own voice sounded faintly. The fact cannot be owing, as has been supposed by some writers, to the bad conducting power of the condensed air, since air conducts sound better in proportion to its density.

The effect of the increased tension of the membrana tympani is not to render both grave and acute sounds equally fainter than before. On the contrary, it was observed by Dr. Wollaston, that, when he had rendered his membrana tympani tense by exhausting the cavity of the tympanum, he was deaf to grave sounds only. By striking the table with the ends of his finger he produced a deep dull note; striking it with his nail, he gave rise to a sharp sound. When he had exhausted the tympanum by the effort of inspiration, he could hear the latter sound only; the former deeper note was inaudible. The heavy rumbling sound produced by the movement of a carriage was not heard in the same condition of the membrana tympani, while the rattling of a chain or loose screw about the vehicle was perceived quite distinctly. These observations are perfectly correct, and will, I believe, be confirmed by every one who has had the necessary practice in such experiments. The effect of forcing air into the tympanum is exactly the same as that of exhausting it, with reference to the perception of grave and acute sounds. Thus the dull rumbling sound of carriages passing over a bridge, or of the firing of cannon, near my house, and the beating of drums at a distance cease to be heard immediately on tension of the membrana tympani being induced in either of the ways above mentioned. But the treading of horses upon the stone pavement, the more shrill creaking of carriages, and the rattling of paper, I hear very distinctly while my membrana tympani remains tense. The character of the deafness is very strikingly shown by the fact, that the ticking of a watch is heard at the distance of eight feet quite as distinctly when the membrana tympani is rendered tense as in the natural state, perhaps even more distinctly, while all dull grave noises in the street cease to be heard.

This difference in the loudness of acute and grave sounds, under the conditions here stated, is easily explicable according to the principles stated at page 1256. The greater the tension to which the membrana tympani is subjected, the more acute will become its fundamental note, and all the harmonic notes also which it is capable of emitting when divided by nodal lines into separate vibrating segments; and in the same ratio will its property of repeating perfectly the vibrations proper to the

deeper notes diminish. The nearer a sound approaches to the fundamental note proper to the tense membrana tympani, the more distinctly it will be heard when the membrane is in this tense condition.

These facts admit of a practical application in pathology. It is not very rare to meet with persons who are deaf to the more grave sounds only, while they still hear distinctly acute sounds, even though they be not loud. One of my colleagues, who is deaf, hears acute better than grave sounds. In such cases it is very probable that the membrana tympani is in a state of too great tension. In the present state of obscurity of the diagnosis of diseases of the ear, this hint may be of some use. Such unnatural tension of the membrana tympani may, of course, be produced by several different causes. It may arise from occlusion of the Eustachian tube; in which case the air in the tympanum may either be expanded by the heat of the body, and so force outwards the membrana tympani, or it may be partially absorbed, when the membrane would be pressed inwards by the air without. Another cause may be a contracted state of the tensor tympani muscle. In my colleague the Eustachian tube is free, for he can force air into the tympanum. When the Eustachian tube is closed, and the tension of the membrana tympani is the consequence of the expansion or partial absorption of the air in the cavity of the tympanum, the operation of puncturing the membrane, or the mastoid process, may be easily conceived to be beneficial; but when the too great tension of the membrana tympani, and consequent deafness, are owing to a contracted state of the tensor tympani muscle, the operation must be useless. This may in part account for the various results obtained from it.

The influence of the musculus tensor tympani in modifying hearing may now be estimated.

If we admit, as a very probable supposition, that the tensor tympani may through reflex nervous action be excited to contraction by a very loud sound, just as the iris and orbicularis palpebrarum muscle are by a very intense light, the impression being conveyed by the sensitive nerve to the brain, and thence reflected upon the motor fibres; then it is manifest that a very intense sound would, by exciting a reflex action of this muscle, induce a deadening or muffling of the ears. A loud sound excites by reflection nervous action, winking of the eye-lids, and, in persons of irritable nervous system, a sudden contraction of many muscles. The above supposition has, therefore, great probability in its favour.* Increased tension of the membrana tympani by the tensor

* A very loud noise, such as that of a cannon, if near, may, by forcing in the membrana tympani, give rise to the production of a new sound by that membrane itself; at least, I think, I have observed this in my own person. At the time of the report of a cannon I perceived a cracking or jerking sound, similar to that which is heard

tympani muscle, by whatever cause excited, must moreover cause the graver sounds, rather than the more acute, to be heard faintly.

We have now to inquire whether the tensor tympani is subject to voluntary influence. Like the stapedius, it presents under the microscope, according to my observations, the characters common to all muscles of animal life; its primitive fasciculi are regularly marked with the cross striæ. The so-named laxatores tympani are, on the contrary, not muscles. In the *musculus mallei externus* I could recognise none of the characters of muscle which are so evident in the tensor tympani; it is a mere ligament. The two real muscles of the ossicula, however, belong without doubt to the system of animal muscles. It is true, that the muscles of the vascular system, the heart, and lymphatic hearts, have likewise primitive fasciculi marked with transverse striæ;—that this character is not confined to the muscles of the parts developed in the external serous layer of the germinal membrane, but also prevails in those formed from the middle vascular layer. But the primitive fasciculi of the organic muscular fibres of internal viscera are constantly devoid of the transverse striæ.* Moreover, the small muscles of the external ear are subject to the will; (I can move them, more especially the *m. antitragicus*, distinctly;) there can therefore be no reason to deny a similar subjection of the muscles of the tympanum to the will. As a circumstance in favour of such a voluntary influence over these muscles existing, may be noticed the origin of the nerve of the tensor tympani from the third branch of the fifth,—namely, from the internal pterygoid nerve; and the origin of the nerve of the stapedius muscle from the facial.

The opinion that the tensor tympani muscle is subject to the influence of the will was held by Fabricius ab Aquapendente, who maintained that he had himself voluntary power over it, he being able to produce a peculiar noise in his ears at will. Fabricius could perform the movement only on both sides simultaneously. Mayer was acquainted with a gentleman who had such power over the motions of the small bones of his ear that another person could distinctly hear the sound thus produced when their ears were applied to each other.† I have the same power of producing at will a sound in either ear, more particularly in the left, in which I can excite it without causing it on the other side. The sound is of a snapping character, like that emitted by the electric spark, or that produced when the end of the finger, rendered adhesive, is pressed upon paper and then suddenly

when the movement of inspiration is suddenly performed while both the nostrils and mouth are closed, so as to draw inwards, and thus render tense, the *membrana tympani*.

* [See explanation of plate II. fig. 9.]

† Compare Lincke, *Handbuch der Ohrenheilkunde*; Leipz. 1837; 1, p. 472.

removed. Another person can hear this knocking or snapping sound by interposing a conducting rod between my ear and his own, both his meatus having been previously closed by plugs: he can also hear it when he places his ear, not stopped, near mine, or even at the distance of one or two feet from it. One person distinguished the snapping sound in my ear at the distance of three feet, our ears being placed directly opposite to each other. Each time that I made the movement in my ear he declared that he heard the sound.

We have now to adduce the arguments in favour of this sound being really caused by contraction of the tensor tympani muscle, and its action on the membrana tympani, which it draws inwards, and thus influences in the same manner as an impulse from without. A circumstance favourable to this view is the occurrence of the same sound at the moment of allowing the air to escape, and the membrana tympani therefore to resume its natural position after it has been pressed outwards, by forcing air into the tympanum from the throat while the mouth and nostrils were closed; the sound then heard is quite distinct from the buzzing of the air rushing against the membrana tympani, and is audible to a second person. On observing the condition of the fauces by means of a mirror during the production of the snapping sound in the ear, I found that the soft palate was raised at the same moment. This naturally suggests the notion that a current of air may be forced into the Eustachian tube by the elevation of the velum palati. But this idea is at once shown to be incorrect by the fact that the soft palate may be raised with great force without the sound in question being produced in the ears. Thus, while singing with the mouth wide open before a mirror, I can perceive that during the production of the high falsetto notes, even with a low voice, the palate is very much elevated, without the snapping sound in the ears being induced; though, by a voluntary effort, it may be caused at the same time. This observation also proves that the phenomenon in question cannot arise from the upper palatine muscles, which arise partly from the cartilage of the Eustachian tube, acting, during their contraction, upon this tube so as to produce a sound which is transmitted to the ear. Such an opinion is, indeed, sufficiently refuted by the fact that the snapping sound produced in my ear is heard by other persons at the distance of several feet. Its cause appears therefore to me to be a voluntary contraction of the tensor tympani muscle.*

Among the movements which induce the snapping sound by asso-

* On more mature consideration it appears to me that the reasons above given for the dependence of the snapping sound on a voluntary action of the musculus tensor tympani do not amount to an absolute proof. [Note in the Addenda of the original work.]

ciation, deglutition must be mentioned ; but it is not a constant and necessary attendant on the movement of deglutition. Besides the snapping sound above described, I am able to produce at will another different noise in the ear, and upon both sides simultaneously. It is of a humming or buzzing character, and can be prolonged for the space of a second or more. Its production is likewise accompanied by elevation of the soft palate, and appears to be owing to the contraction of the palatine muscles. This humming or buzzing sound occurs sometimes during yawning and eructation, even when this movement is voluntarily induced.

During the production of the snapping sound my hearing for other sounds is not perceptibly affected, but the humming sound just referred to interferes with hearing.*

An involuntary contraction of the tensor tympani muscle, like its action under the influence of the will, must produce a sound. Many persons will have observed noises in their ear from this cause.†

The influence of the stapedius muscle in hearing is unknown. It acts upon the stapes in such a manner as to make it rest obliquely in the fenestra ovalis, depressing that side of it on which it acts, and elevating the other side to the same extent. The only effect which, it appears to me, could be ascribed to it, would be to render tense the membrane by which the base of the stapes is connected with the margin of the fenestra.

* The snapping sound may occur simultaneously with the humming or buzzing sound described above, but it may also be produced separately. If I perform the movements necessary for causing both these sounds, and immediately afterwards emit a humming vocal tone while my mouth is either closed or only slightly open, this tone has an extraordinary resonance ; and it is evident that the movements just mentioned have effected some change, in consequence of which a part, which previously had only very slight or no effect on the intensity of sounds, acquires a great influence on them. The sound of one's own voice by this means acquires the intensity of the tones of an organ. The movement which produces the buzzing sound in the ear, and not that which produces the snapping sound, appears to be the cause of the increased resonance ; for I can give rise to the latter separately without influencing the resonance of the voice. I am able also to confine the resonance to either ear. I cannot explain these phenomena. Another circumstance connected with the resonant action of the ear deserves mention. The experiment just described does not readily succeed with every person ; this fact, on the contrary, may be easily verified. If, while the mouth is held closed, any vocal sound be produced in a singing or humming manner, and the external meatus of the ears be closed by the fingers lightly introduced, but not firmly pressed into them, the sound of the voice is heard much louder than before, but with a peculiar dull resonance in the ears, like the tone of an organ. If the fingers are pressed strongly into the ears, the resonance ceases. The resonance may be heard in one ear only, if the finger be applied to the meatus only of one ear. The resonance of the voice produced in this manner is of a similar character to that experienced in the former experiment, but of much less intensity.

† Compare Lincke, *op. cit.* p. 481.

The fenestræ, ovalis and rotunda.

The existence of two fenestræ for the transmission of sound to the labyrinth is not a necessary condition for hearing in animals living in the air, which are furnished with a tympanum; for, as the experiments already detailed prove, both a tense membrane, (such as the membrana tympani secundaria, or membrane of the fenestra rotunda,) and a moveable solid body connected with a tense membrane, are capable of conducting sound with considerable intensity to water. Comparative anatomy also furnishes proofs of the truth of this statement; for frogs in which a tympanic cavity otherwise perfect exists, have no second fenestra, or fenestra rotunda, the chain of auditory ossicula being in them the only means of conducting the sound to the labyrinth. In this case the air in the tympanum can scarcely be regarded as an auxiliary, since its sonorous vibrations cannot be communicated in any intensity to the solid parts of the organ. Its principal use must here be to insulate the small bones of the ear and the membrana tympani.

When both fenestræ exist together with a tympanum, the sound is transmitted to the fluid of the internal ear in two ways,—namely, by solid bodies and by membrane; by both of which conducting media sonorous vibrations are, as my experiments have shown, communicated to water with considerable intensity. The sound being conducted to the labyrinth by two paths will, of course, produce so much the stronger impression; for undulations will be thus excited in the fluid of the labyrinth from two different though contiguous points, and by the crossing of these undulations stationary waves of increased intensity will be produced in the fluid.

It is natural to inquire here by which of the paths above indicated the sounds are conducted with most intensity from the membrana tympani to the labyrinth; whether through the chain of bones and the fenestra ovalis, or through the air of the tympanum and the membrane of the fenestra rotunda.

This question has hitherto been answered for the most part in an arbitrary manner. By some writers the conducting power of the chain of ossicula has been denied, on the ground of hearing having been retained after the loss of those bones, as in the cases observed by Sir A. Cooper,* and previously by Caldani and Cheselden. While others again have denied that sound is transmitted by the fenestra rotunda, because in numerous cases deafness has been the result of destruction and loss of the ossicula.† It would, however be incorrect to ascribe the propagation of sound to either path exclusively, since each part of the apparatus capable of propagating sonorous undulations must con-

* Philos. Transact. 1801.

† See Haller, Element. Physiol. t. v. 285.—Compare Lincke, loc. cit. 465.

tribute to the result in a degree determined by physical laws. The relative conducting power of the different parts is, therefore, all that we have to determine. Muncke* has reviewed the various opinions relative to this question, and the arguments on which they are founded. He himself decides in favour of the chain of ossicula being the principal means of conducting the sound. If we suppose, he says, that any one held two watches, which beat with equal loudness, at the same distance from the ear, one of them, however, being connected with it by means of a rod of bone, the other suspended freely in the air, it is evident that he would hear the first distinctly, the second not at all. Again: We need, he says, only consider the common experiment in which the sound of a spoon, which would not be audible if transmitted by the air only, is heard very loudly in consequence of being suspended by a thread, and connected by this with the ear, in order to come to the conclusion that the sound must be conducted to the labyrinth principally by the ossicula auditus. But the analogy is here not perfect. Sonorous undulations admitted primarily by a solid body are, it is true, conducted to the ear with very great intensity by a solid rod, and very feebly by the air; but, in the same way, sonorous undulations excited in the air are conducted by air much better than by a solid body. The question which we have to determine is, whether sonorous undulations excited in the air, or communicated to it, are transmitted by the membrana tympani most readily to the ossicula or to the air of the tympanum; and whether they are transmitted most readily by the ossicula to the fluid of the labyrinth, or from the air of the tympanum to the same fluid through the membrane closing the fenestra rotunda.

We may express the problem to be decided in other words, thus: By which succession of media is the intensity of sonorous undulations least diminished?—by air, a tense membrane, an insulated and moveable solid body, and water; or by air, a tense membrane, air, another tense membrane, and then watery fluid? The experiments which I have instituted prove very clearly that

V. *Vibrations are transmitted with very much greater intensity to water when a tense membrane, a chain of insulated solid bodies capable of free movement, are successively the conducting media, than when the media of communication between the vibrating air and the water are the same tense membrane, air, and then a second membrane; or, to apply this fact to the organ of hearing, that the same vibrations of the air act upon the fluid of the labyrinth with much greater intensity through the medium of the chain of auditory bones and the fenestra ovalis, than through the medium of the air of the tympanum and the membrane closing the fenestra rotunda.*

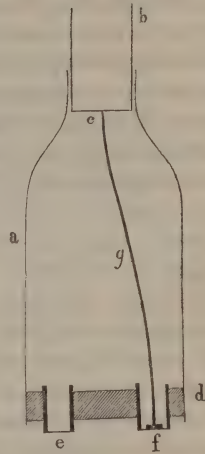
I imitated the structure of the tympanum in the following manner.

* Kastner's Archiv. für d. ges. Naturlehre, 7, 1.

To the neck of a glass cylinder, two inches and one third in diameter and six inches long, *a* (fig. 133), I fixed tightly a wooden tube, *b*, the diameter of whose lumen was eight lines. The upper end of this tube, *b*, was adapted to the mouth of the metal flute-pipe one foot in length; its lower extremity was covered with a tense membrane (of pig's bladder), *c*, which represented the membrana tympani; while the tube itself corresponded to the external meatus, and the cavity of the glass cylinder, *a*, to the tympanum. The lower wide extremity of the glass cylinder was closed by a thick lamina of cork, *d*, in which there were two openings, equally distant from the walls of the cylinder, for the reception of short wooden tubes from three to four lines in diameter. The outer opening of each of these tubes was covered with membrane. The membrane of the tube *f* was brought into connexion with the upper membrane *c*, by a wooden rod *g*, which was in contact with the upper membrane at its middle only, but was connected with the lower membrane *f*, through the medium of a broad plate of wood occupying nearly the entire surface of the membrane. The rod *g* was of such length as to keep both the membranes with which it was connected somewhat tense; it represented the chain of ossicula extending between the membrana tympani *c*, and the fenestra ovalis *f*. The fenestra rotunda was represented by the other short tube, and its membrane *e*. The lower part of the apparatus being immersed in water, and the musical pipe fitted to the tube *b* and sounded, the conditions for the propagation of the sound to the water were the same as in the natural ear for the transmission of sounds to the fluid of the labyrinth. And if, in addition, a space be left at one point between the edge of the lamina of cork *d*, and the glass cylinder, and if this part of the cylinder be raised out of the water during the experiment, while the mouths of the tubes *e* and *f* remained immersed, the air in the interior of the cylinder *a* will be brought into communication with the external air, just as the air of the tympanum is by means of the Eustachian tube. The presence or absence of this communication, however, makes no difference in the result of the experiment.

My ears being stopped by plugs, I could, by means of a conducting-rod held in connexion with one ear, ascertain the relative intensity of the sonorous vibrations communicated to the water through the two openings *e* and *f*, corresponding to the fenestra rotunda and the fenestra ovalis, while another person sounded the pipe. The difference was very striking. The sound transmitted by the wooden rod to the

Fig. 133.



opening *f* was in a remarkable degree louder than that propagated through the air of the cavity and the membrane of the opening *e*. The loud sound issuing from the opening *f* was heard even opposite the opening *e*; hence, to ascertain the strength of the sound issuing from the latter separately, it was necessary to remove the rod from the apparatus, and to close completely the opening *f*, corresponding to the fenestra ovalis, by means of a solid plug. It was then found that the sound was transmitted by the membrane *e* (the fenestra rotunda), with but little more intensity than by the solid lamina of cork itself. The same sound may possibly be communicated to the labyrinth by the two fenestræ, not only with a different intensity, but also with a somewhat different quality or "timbre." The undulations transmitted by the fenestra rotunda are undulations of air up to the point of their reaching the membrane of this fenestra. Those transmitted by the fenestra ovalis are, on the contrary, undulations of solid bodies,—the ossicula auditus. Now, it is well known that one and the same sound may be modified in "timbre" by the resonance of different bodies. What a different character, for example, has the sound produced by a vibrating tuning-fork, according as it is held free over a bowl containing air only, or approximated to the walls of the same vessel! How differently does a bell rung in water sound, according as its sound is conducted to the ear by a solid rod, or only by the air! In the first case the sound is loud and full, in the second it is feeble. It is difficult to ascertain by direct experiment how far the sounds transmitted by the two fenestræ in the above described apparatus differ in "timbre;" since, to compare sounds in this respect, they should be of equal intensity. The experiments which I have instituted were, however, favourable to the opinion of such a difference in "timbre" existing, rather than opposed to it.

The undulations transmitted by the fenestra ovalis act primarily upon the vestibule and the semicircular canals; those transmitted by the fenestra rotunda, upon the cochlea: but those communicated immediately to the fluid of the vestibule, inasmuch as they extend as circular waves in the fluid, must ultimately reach the cochlea; and the relation of the fenestra rotunda to the cochlea is by no means constant, since in chelonian reptiles (tortoises and turtles) both fenestræ exist, though there is no proper cochlea.

The Eustachian Tube.

The Eustachian tube is never absent when the tympanum exists. Its great importance in rendering hearing perfect is proved by the circumstance of the occlusion of it, as a consequence of disease, being always attended with deafness and tinnitus. But it cannot, from these cases of disease, be determined whether the Eustachian tube is itself

essential to the hearing of sounds with distinctness and intensity, or whether its occlusion affects hearing only indirectly.

It may be easily conceived that the ill effect of obstruction of this passage would be equally great whether its office were merely to prevent the production of too great tension of the *membrana tympani* by expansion or condensation of the air in the tympanum, or to carry off the mucus generated in that cavity by the ciliary motion of its mucous lining. All the provisions by which the tympanum has been adapted to the better propagation of sound would be rendered unavailing if it were to become filled with mucus.

The different offices which might be, and have been, attributed to the Eustachian tube are the following: we shall consider them in succession.

1. Some writers have imagined that a body of air inclosed on all sides is not adapted for the transmission of sonorous vibrations. Thus Saunders* says, that when the Eustachian tube is obstructed, "the included air, incapable of yielding in any other way than by condensation, counterbalances the pulses excited by sounding bodies." This supposition is, as Muncke remarks, directly contradictory to the laws of physics; for no displacement of the air is necessary in the propagation of an impulse.

2. According to the laws of physics, the very opposite of the foregoing view would be more probable; for if the conducting chain of ossicula be left out of consideration, and the cavity of the external meatus and tympanum be compared to that of a tube used for conducting the voice to a distance, in which the sonorous undulations, on account of the column of air propagating them being insulated, are transmitted with their full intensity, the presence of an opening from the exterior into the cavity of the tympanum ought to cause a partial dispersion of the undulations, as a similar opening into such a tube would, and therefore, in the case of a violent impression of sound, render their effect, as far as it is felt by the *fenestra rotunda*, less intense.

3. Other authors, among whom is Muncke,† imagine that unequal density of the air within, and of that without the tympanum, would be an impediment to hearing. To this opinion also I cannot subscribe. Sound, in passing through strata of air of different densities, appears certainly to lose somewhat of its intensity; but by the mere presence of a membrane, such as the *membrana tympani*, between two bodies of air even of equal density, the medium of transmission is already rendered threefold. The undulation has to be communicated from air to the membrane, and from the membrane to air again; and the

* *Anatomy of the Human Ear*; London, 1806.—Second edition, 1817, p. 79.

† *Op. cit.* 26.

important circumstance is not the degree of difference between the one body of air and the other, but the degree of capability of the second body of air (the air within the tympanum) to become affected with undulatory motion communicated to it by the membrane.

4. According to another view, the Eustachian tube is destined to prevent the resonance of the air in the tympanum. This opinion is, however, least of all tenable; for a body of air is capable of resonance, whether the cavity containing it be open at one or both ends. Simple resonance, so as to increase the intensity of the sound, would be rather an advantage than the contrary. It is only the sympathetic vibration of a body of air in its own proper note which would disturb the integrity of hearing. With reference to this sympathetic vibration of a body of air, it is to be observed, that the column of air of an open tube is to be regarded as equal to that of a closed tube of half the length.

5. A fifth view would regard the Eustachian tube as destined to increase the resonance of sounds in the ear. Thus Henle* compares it to the apertures in the sounding-board or belly of a violin, which are so necessary to give the instrument strength and fulness of tone, by causing the air contained in the body of the violin, as well as the mere sounding-board, to reinforce the sound by resonance. Henle supposes that the air of the cavity of the mouth and nose are in like manner enabled, through the medium of the Eustachian tube, to increase by resonance the intensity of sounds entering the ear through the external meatus. The possibility of such a mode of action cannot be denied. Direct experiments upon the influence of a side tube communicating with a short main tube, in rendering the resonance greater, are favourable to the view in question. The sound of a tuning-fork held over the mouth of a short tube (four inches long and one inch wide) seemed to me to be louder when a second longer tube (two feet in length) was connected with it at an opening in its side, than when this side opening existed and no second tube was connected with it. If the opening between the tubes was very small, no difference in the sound was perceived.

Direct experiments are capable of being instituted to determine whether the resonant influence of side cavities is not for the most part rendered null, when the opening of communication is so small as that of the Eustachian tube. A rough model of the tympanum, with the Eustachian tube, may be constructed in the following manner:—

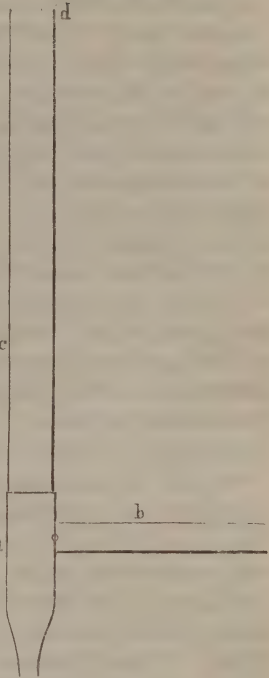
A wooden tube, *a*, measuring eight lines in diameter, and three inches in length, and contracted towards one extremity, so that it may be inserted deep into the external meatus, is closed at its wider extremity by a membrane. In the side of this tube, which

* Encyclop. Wörterbuch der Medic. Wissensch. art. Gehör.

represents the cavity of the tympanum, is a very small opening; and at this point a second tube, *b*, can be connected with it. The tube *c*, which serves the purpose of the external auditory passage, receives, by its lower extremity, the large end of the tube *a*, which is fitted tightly into it.

The sound, by means of which the influence of this apparatus is to be estimated, must not be excited in the free space of the surrounding air, for then it would reach the ear through the tube *b*, or, when this is removed, through the small opening in the tube *a*, as well as through the pipe *c*, which represents the external auditory passage. It must be produced within the tube *c*, in such a manner as to extend but little beyond it. The best mode of fulfilling this condition I found to be, to cause an assistant to apply his lips closely to the mouth of the pipe *d*, and, while he closed his nostrils, to strike his teeth together so as to produce a noise, which was imparted to the air in the tube. The contact of the soft parts of the lips with the tube *c* prevents the sound from being communicated to the walls of that tube; while, by the air of the tube, it is conducted to the membrane, and to the air of the tube *a*, which represents the tympanum. The narrow part of the tube *a* being fixed firmly in my ear, I compare the differences of the sounds transmitted to it when the side opening in the tube *a*, or tympanum, is closed, when it is open, and when the side tube *b* is affixed. The sound I find is duller when the side opening which represents the opening of the Eustachian tube into the tympanum, is closed than when it is open; but there is little or no difference in its intensity. The difference is much less between the sound heard when the side tube is affixed, and that heard when the orifice is merely open without the side tube being placed over it; the "timbre" is here in both cases the same, and there is no perceptible difference in intensity,—at least, no decided difference. When, therefore, the opening between a cavity representing the tympanum, and a side cavity, *b*, is very small, the latter cavity loses all, or nearly all, its influence by resonance upon a sound which is not communicated directly to it.

Fig. 134.



6. The most generally adopted view of the office of the Eustachian tube is, that it does away with an impediment which a body of air con-

fined on every side in the tympanum would offer to the propagation of sound, by diminishing either the original vibrations of the membrana tympani itself, or the resonance of that membrane, and of the air of the tympanic cavity. Itard illustrated this view by reference to the soldier's drum, which yields only a dull and faint sound when the opening in its side is closed. This example, however, bears little analogy to the case it is intended to elucidate; for, if the sound of a drum were louder when it has a side opening, this would be owing to the vibrations of the air within the drum being communicated better to the atmosphere and ear by air itself, than by the solid walls of the drum and its membranes (parchment heads). Moreover, I find the difference between the sound of a small drum, when its side hole is open, and when it is closed, very slight, amounting to a scarcely perceptible difference in "timbre." No increase in the intensity of sounds can be supposed to be produced by the sonorous undulations entering the mouth and nostrils being transmitted to the tympanum through the Eustachian tube; for a person whose organs are perfectly healthy hears as well when his mouth and nostrils are closed as when they are open.

Several experiments which I have instituted are not favourable to the opinion, that the presence of the Eustachian tube renders the sounds transmitted through the membrana tympani more intense. A short tube, with a side opening like the portion *a*, in fig. 134, was inserted deep into the ear, and a sound excited upon the membrane closing its outer extremity, while the other ear was stopped with a plug of chewed paper. A sound produced in the surrounding atmosphere could not, of course, be made the subject of comparison, since it would be transmitted through the side opening of the tube to the air in its interior with greater intensity than through the membrane at its extremity. It was found, however, that a sound excited in the membrane itself by striking or rubbing it with the finger, was always heard with a dull tone when the side opening of the tube was closed, and with a clear, and, as it were, sharp character, when the same orifice was open. But there was no difference in its intensity; on the contrary, when the membrane was moistened, the dull sound heard with the side orifice closed seemed to me to be louder than the clear sound heard with it open. The result was the same when the experiment was performed with the apparatus represented by fig. 134, in the manner before described. The sound heard when an assistant applied his lips to the mouth of the tube *d*, and struck his teeth together while his nostrils were closed, (the end of the tube *a* being fixed in the experimenter's ear, and the side tube *b* removed,) had a duller character when the side orifice was closed than when it was open; but it did not differ perceptibly in intensity.

We may, therefore, admit that a certain degree of dulness, which

the sound might acquire from the resonance of the apparatus of the tympanum, is avoided by the presence of the Eustachian tube; but that this tube tends to increase the intensity of the sound, as the above-mentioned hypothesis supposes, cannot be conceded. Some other experiments, also, on the organ of hearing itself, in which the Eustachian tube is closed or left open, tend to confirm the above conclusion, at which we have arrived. The most certain method of ascertaining the function of the Eustachian tube would undoubtedly be to close the Eustachian itself artificially, but in such a way that the pressure of the air in the tympanum should not thereby be increased, and greater tension of the membrana tympani produced. But this is scarcely possible; and, besides, the experimenter who allowed his Eustachian tube to be catheterized, could never be perfectly sure whether or not the instrument was really in the canal. This idea may, therefore, be at once renounced, as little calculated to advance physiology. Pathological observations, again, have hitherto afforded but little aid in solving the difficulty. The injection of water into the Eustachian tube was observed by Cheselden to produce immediate deafness. Saunders, on the contrary, states that this operation on a person labouring under deafness was followed by an improvement of hearing, which lasted as long as the fluid was retained in the ear. This discrepancy in the results seems to have another cause than the mere occlusion and opening of the Eustachian tube. More importance was probably due in these cases to the state of tension of the membrana tympani, which might have been increased by the operation; or if the pressure of the air within the tympanum had previously been less than natural, so that the membrana tympani was pressed inwards, diminution of its tension might be produced by the injection of the water increasing the pressure of the air within. There is, however, a means of producing at will either occlusion or dilatation of the Eustachian tube, with equal though increased tension of the membrana tympani. By making an effort at inspiration, while the mouth and nostrils are closed, the air in the tympanum is rarefied, and at the same time the sides of the Eustachian tube collapse, which is known by the sensation due to the tension of the membrana tympani continuing after the cessation of the movement of inspiration until voluntarily removed by an effort in the ear (see page 1259). On the other hand, by a strong effort of expiration, the mouth and nostrils being closed as before, the Eustachian tube may be dilated beyond its ordinary size; here, also, the membrana tympani is rendered tense: the conditions of the tympanum are, therefore, with the exception of the state of density of the air, nearly the same in both cases. In both the membrana tympani is more tense than natural; but in one the tuba Eustachii is dilated, in the other it is closed. Hearing, however, is equally impaired in both states.

7. The opinion that the Eustachian tube is destined for the transmission of the sound of the individual's own voice to his ear, would seem to be sufficiently refuted by the experiment performed long since by Schellhammer. He introduced a vibrating tuning-fork into the interior of his mouth, and found that its sound was in that situation scarcely heard. Held in front of the mouth moderately open, it sounds very loudly, in consequence of the resonance of the air in the cavity, just as the air of a bottle renders the sound of a tuning-fork held near its mouth much louder. But in this case, also, the sound is conveyed to the tympanum principally through the medium of the external ear. The ticking of a watch also held in the mouth, in such a manner that it does not touch the teeth or tongue, is scarcely heard. Schellhammer's experiment is not, however, conclusive; for the sound of the tuning-fork, like all sonorous vibrations of solid bodies, is not readily imparted to the air; while the vibrations of the vocal cords, like those of all reed-instruments, excite regular sympathetic vibrations of the air itself. There is another method, however, by which we may satisfy ourselves that the influence of the Eustachian tube in rendering the individual's voice audible to himself, is very slight. The Eustachian tubes may, as we have already described, be closed or opened at will by the aid of certain movements of inspiration. The tubes being closed by an effort of inspiration, or opened by an effort of expiration, we have merely, while the mouth and nostrils are still held closed, to produce a vocal sound, (which can be effected at least with the character of a short humming sound,) when we shall perceive that in either case we hear our voice quite distinctly. The difference in the sound is very trifling, its intensity being in a slight degree greater when the Eustachian tubes are wide open than when they are closed. It is certain, therefore, that these tubes are not the principal route by which our own voice is conducted to our ears. Our voice is heard partly through the medium of the external meatus; it spreads forth from the mouth in circular waves, the hinder portions of which fall upon the concha, and are reflected by it towards the tragus, and thence into the external meatus.

The concha of the external ear appears to me, indeed, to have the very position best adapted for reflecting towards the meatus the sonorous undulations issuing from the mouth. The sound of our voice is, however, communicated from the air in our nostrils and mouth to the walls of these cavities, and thus also through the cranial bones to the ear, and again, in a still more direct path, by a chain of solid parts from the vocal cords to the labyrinth. The great share which this mode of propagation must have in conducting the sound of our voice to the ear may be inferred from the distinctness with which we hear sounds produced in situations wholly surrounded by the solid parts of our body, such

as borborygmi in the intestines. A still better conception of the propagation of the sound of our voice to our ear through solid parts may be obtained by closing both ears with plugs, and interposing a conducting-rod between one ear and the larynx of another person while he speaks. His voice is then heard just as we hear our own. Autenrieth* and Lincke† have observed that, when the Eustachian tubes are obstructed in consequence of diseased action, external sounds are rendered indistinct, but that the patient hears his own voice well.

8. That the Eustachian tube has the office of conveying away mucus secreted in the cavity of the tympanum by means of cilia vibrating on its surface, cannot be doubted; and the deafness consequent on occlusion of the tube is in part explicable by the tympanum becoming then filled with mucus. But this cannot be the sole office of the passage.

9. The principal object for the fulfilment of which the Eustachian tube exists, wherever there is a tympanum, appears to me to be the maintenance of the equilibrium between the air within the tympanum and the external air, so as to prevent inordinate tension of the membrana tympani, which would be produced by too great or too little pressure on either side, and the effect of which would be imperfection of hearing. It is not the increased or diminished density of the air on either side of the membrane which is of the chief importance, but the tension of the membrana tympani which they necessarily produce, and which always interferes with the integrity of hearing.

It is on this principle that we must explain the good effect of catheterizing the Eustachian tube, or of perforating the membrana tympani, or mastoid process of the temporal bone, in many cases of deafness caused by chronic occlusion of the tube. While, however, I maintain that this is the principal office of the Eustachian canal, I do not deny that it has other uses, of which the next in importance appear to me to be the modification of the sound so as to render it more clear, the supplying the tympanum with air, and the discharge of the secretion of that cavity.

When the Eustachian tubes are sufficiently wide, the density of the air within the tympanum will be kept constantly equal to that of the external air; and, when the latter rapidly increases in density, the air within the tympanum will immediately acquire the same density, so as to balance the increased external pressure upon the membrana tympani, without our being conscious of any change. In proof, however, that in other cases the balance of the pressure within the tympanum and upon its exterior may be disturbed, the observations of persons who have descended in the diving-bell (see page 1260) may be adduced.‡ Carus §

* Reil's Archiv, ix. 321.

† Op. cit. p. 502.

‡ [See also Dr. Todd's observations in the Cyclopædia of Anat. and Physiol. art. Hearing, p. 575.]

§ Bericht über die Versammlung der Naturforscher in Jena.

also, in ascending high mountains, perceived a sensation of tension in the ears; and, after a certain height was attained, a snapping sound, which was repeated at elevations differing about six hundred feet from each other. Whether these sensations be perceived or not by others, will, of course, depend in part on differences of individual conformation. I do not myself recollect to have experienced anything of the kind. Before, however, the state of disturbed balance of pressure had reached its maximum, I should remove it by a voluntary action of the tensor tympani (see page 1262), which is also attended in me with a snapping sound.

Muncke supposes that the membrane of the fenestra rotunda serves by its elasticity to moderate the effects of a violent impulse communicated to the fluid of the labyrinth. An opening in the side of a tube filled with air and conducting sound, is certainly calculated to divert the sonorous vibrations which are otherwise kept insulated within the tube on account of the difficulty with which undulations are communicated from air to solid bodies; but undulations of condensation and rarefaction produced by an impulse in water are imparted with facility to solids.

The external auditory passage.

The meatus auditorius externus influences the propagation of sound to the tympanum in three ways: 1, inasmuch as the sonorous undulations entering directly from the atmosphere are transmitted by the air in the tube immediately to the membrana tympani, and are prevented from being dispersed; 2, by the walls of the passage conducting the sonorous undulations imparted to the external ear itself by the shortest path to the place of attachment of the membrana tympani, and so to this membrane; 3, by the resonance of the column of air contained within the passage.

As a conductor of undulations of air, it receives the direct undulations of the atmosphere, of which those which enter in the direction of the axis of the canal must produce the strongest impression. The undulations which enter the passage obliquely will be reflected by its parietes, and will thus by reflexion reach the membrana tympani. By reflexion, also, the external meatus receives the undulations which impinge upon the concha of the external ear, when their angle of inflexion is such that they are thrown towards the tragus. Other sonorous undulations again, which could enter the meatus from the external air neither directly nor by reflexion, may still be brought into it by "inflexion;" undulations, for instance, whose direction is that of the long axis of the head, and which pass over the surface of the ear, must, in accordance with the laws of "inflexion," be bent into the external meatus by its margins. The action of those undulations will, however, be most intense which enter the meatus directly, neither by reflexion nor inflexion. Hence we are

enabled to judge of the point whence sound comes, by turning one ear in different directions.

We have next to consider the walls of the meatus as solid conductors of sound; for those vibrations which are communicated to the cartilage of the external ear, and not reflected from it, are propagated by the shortest path through the parietes of the auditory passage to the membrana tympani. Hence both ears being close stopped, the sound of a pipe is heard more distinctly when its lower extremity covered with a membrane, is applied to the cartilage of the external ear itself, than when it is placed in contact with the surface of the head.

Lastly, the external auditory tube is important, inasmuch as the air which it contains, like all insulated masses of air, increases the intensity of sounds by resonance. To convince ourselves of its really having this influence, we need merely lengthen the passage by affixing to it another tube. Every sound that is heard, even the sound of our own voice, is then much increased in intensity. If tubes of considerable length are used, and their length is adapted to the sound, the column of air in them will reciprocate it by their own fundamental notes, as the MM. Weber have shown. Shorter columns of air do not thus reciprocate sounds, but merely increase their intensity by resonance.*

Cartilage of the external ear.

The action of the external ear upon sonorous vibrations is partly to reflect them, and partly to condense and conduct them to the parietes of the meatus externus. With respect to its reflecting action, the excavation called the concha is the most important part, since it directs the reflected undulations towards the tragus, whence they are thrown into the auditory passage. The other inequalities of the external ear do not promote hearing by reflection;† and, if the conducting power of the cartilage of the ear were left out of consideration, they might be regarded as destined for no particular use; but, receiving the impulses of the air, the cartilage of the external ear, while it reflects a part of them, propagates within itself and condenses the rest, as all other solid and elastic bodies would do. This action of the cartilages of the external ear is with justice insisted on by M. Savart. The sonorous vibrations which it receives by an extended surface are conducted by it to its place of attachment. The mode of propagation of the impulses in the cartilage of the ear may be illustrated by reference to Savart's investigations concerning the propagation of undulations in bodies formed of branches having different directions, the results of which I applied to the explanation of the propagation of sound by the ossicula auditus. The undulations

* See note to page 1264. [The resonant action of the meatus, particularly when lightly closed, was pointed out by Mr. Wheatstone, in the *Journal of Science and Arts* for 1827, vol. ii. New Series.]

† See Esser, in *Kastner's Archiv*, xii.

communicated to the cartilaginous external ear will not follow its various curves, but will traverse it in their own original direction, causing the neighbouring parts of the cartilage also, whatever their position, to be thrown into a vibratory movement which has exactly the same direction. This propagation of the movement is continued from particle to particle even to the interior of the ear, the membrana tympani, and the bones of the head. In consequence of the connection of the parietes of the auditory passage with the solid parts of the whole head, some dispersion of the undulations will result; but the points of attachment of the membrana tympani will receive them by the shortest path, and will as certainly communicate them to that membrane, as the solid sides of a drum communicate sonorous undulations to the parchment head, or the bridge of a musical string its vibrations to the string.

Regarding the cartilage of the external ear, therefore, as a conductor of sonorous vibrations, all its inequalities, elevations and depressions, which are useless with relation to reflexion, become of evident importance; for those elevations and depressions upon which the undulations fall perpendicularly, will be affected by them in the most intense degree; and, in consequence of the various form and position of these inequalities, sonorous undulations, in whatever direction they may come, must fall perpendicularly upon the tangent of some one of them. This affords an explanation of the extraordinary form given to this part.

The external ear of many animals is in every respect comparable to an ear-trumpet capable of being directed different ways at will, in which the undulations of the air are propagated onwards and concentrated at the same time, and whose parietes also are capable of transmitting the sonorous vibrations communicated to them. Moreover, this form of ear, like the ear-trumpet, lengthens the column of air of the auditory passage, and increases the influence which its resonance has in rendering the sound more intense.*

*Solid bodies and masses of air in the neighbourhood of the labyrinth
influencing sounds by their resonance.*

In this light we must regard, not merely the cranial bones, but all cartilages and membranes in the vicinity of the organ of hearing.

By the resonance of bodies of air occupying cavities within the head our voice is rendered more audible, not merely to others, but also to ourselves. Any mass of air bounded by a different medium is excited to resonance by a sound produced near it. If a vibrating tuning-fork is held over the mouth of an apothecary's phial, the air within it gives great increased loudness to the sound by resonance; while, if the tuning-fork is merely

* The great influence of the insulated column of air in increasing the intensity of the sounds is frequently overlooked in the case both of the ear-trumpet and of the speaking-trumpet.

brought near the side of the phial, the resonance is much less marked. The resonance of the column of air in a tube open at one or both extremities is very strong. So, also, if a tuning-fork is held, while vibrating, close in front of the mouth, great resonance is produced, which is heard as well by the experimenter as by a by-stander.* Whereas, if it is introduced quite into the interior of the mouth while this is held wide open, the sound heard is remarkably faint, not only to the ear of other persons, but to that of the individual himself. The circumstance of persons whose hearing is bad holding their mouth open while listening, appears to have some connexion with the resonant power of the air in the mouth : it cannot have reference to the transmission of the sound through the Eustachian tubes, since a tuning-fork vibrating even at the back of the mouth is heard but faintly. The habit of holding the mouth open in persons whose hearing is imperfect, may, however, have for its object more particularly to dilate the cartilaginous portion of the auditory passage, which, as Elliot remarks, is effected by opening the mouth.

At all events, the intensity which the voice of another person acquires when he speaks through a tube placed in front of our mouth or nostrils, must depend in part on the resonance of the cavities containing air which lie in our head.

Even the air in the external auditory passage and in the tympanum has an action of resonance. This is perceived when we simply elongate the auditory passage by inserting a tube into it. We then hear not merely the sound of the circulation in the ear, and of the slight movements of the air apparently at rest, which, without being necessarily sonorous undulations, produce a sound in the tube, just as a sound is produced in a musical pipe by a blast of wind ; but every sound, as well that of our own voice as of external bodies, is accompanied by a distinct resonance. The same influence of the air of the meatus auditorius in increasing the intensity of sounds by resonance may be shown by shortening the column of air in the meatus by means of a plug inserted deeply, as well as by lengthening it ; for, when the external auditory passages are thus plugged, not only are all external sounds rendered indistinct in consequence of the propagation of the undulations of the air to the membrana tympani being interrupted, but also the sound of our own voice is heard indistinctly and feebly. This cannot be wholly owing to the sonorous undulations issuing from our mouth being no longer admitted into the external meatus ; for, though the undulations

* The sound thus produced resembles the sound of the letter *u* broad, or *oo*, when the opening of the mouth is small, and that of a *broad* when it is wider. The sound produced by holding a vibrating tuning-fork over a tube three and a half inches in length, and eight lines in diameter throughout, which is set upon a table, is likewise similar to that of the vowel *u* when the opening of the tube is narrowed by the hand, and more similar to a *broad* when the opening is left entirely free.

spreading out in circles from our lips do in the natural condition partly reach the external auditory meatus by reflexion from the concha towards the tragus, and by inflexion, yet their entrance into the auditory passage may be entirely prevented by holding the flat hands close in front of both ears, and our voice will still sound loudly to us if the whole meatus be full of air, so as to reinforce the sound by resonance. The want of the resonant body of air in the meatus must therefore be in part the cause of the indistinctness and faintness of our own voice when our ears are plugged.

The propagation of sound to the labyrinth through the cranial bones compared with that through the tympanum.

By the apparatus of the tympanum sonorous vibrations are communicated to the labyrinth on its external side, through the medium of the fenestræ, whence they spread in all directions through the perilymph or aqua Cotunnii.

The cranial bones, which in the osseous fishes are the only medium through which sound can reach the labyrinth, communicate the sonorous vibrations to it with equal facility on every side. Sound is conducted to the labyrinth in this way in animals living in the air also, but with very little intensity, on account of the difficulty with which vibrations of the air are communicated to the solid parts of the head. We have no means of ascertaining the degree of intensity with which sounds would be heard through the medium of our cranial bones alone; for, even when our ears are close stopped, the cartilage of the external ear still conducts the sound better than the cranial bones, and the insulated ossicula in the tympanum make a stronger impression on the labyrinth than the cranial bones, which are not thus insulated. The reinforcing power of the chain of small bones of the ear may come into play even when the sonorous undulations of the air are communicated primarily to the bones of the cranium; for, even in this case, the undulations are conducted by the latter bones to the membrana tympani and the ossicula, and are reinforced by the resonance of the apparatus of the tympanum. The same is the case with the sonorous undulations of our own voice, which, being communicated to the parts surrounding the mouth, throat, and nostrils, excite resonance of the acoustic apparatus of the tympanum. Undulations imparted to the bones of the head by solid bodies also are reinforced by resonance in the tympanum. A vibrating tuning-fork applied to the head, while both ears are stopped, is heard most faintly at the vertex, more loudly when placed upon the temple, and with more and more intensity the nearer it is brought to the meatus externus of the ear, and not merely in proportion to its approximation to the labyrinth.

For sounds to be heard through the medium of the cranial bones

alone, it would be necessary for the apparatus of the tympanum to be absent, as well as the external meatus closed. It is probable that sounds propagated by the air would then either be inaudible, or be heard with excessive faintness; while the sonorous vibrations of solid bodies conducted by solid media to the head would still be audible if the labyrinth were free from lesion. This test might be employed in cases of deafness, to ascertain whether the labyrinth and auditory nerve are sound.

A deaf person, who is unable to hear any sound through the medium of the atmosphere, is nevertheless sometimes able to perceive the sound of strong blows upon the ground or floor, owing to the vibrations being conducted to his ear through the solid parts of his body. There is here a difficulty, however, in distinguishing between the perception of vibrations by the sense of touch and by the sense of hearing. All grave sounds act readily upon the nerves of touch; the sonorous vibrations are felt distinctly as tremors when the hand is applied to the thorax while speaking, or when a solid body emitting a sound is held in the hand. The sonorous vibrations excited in water by means of a musical pipe are not sensible to the touch when the hand is dipped in the water, but are perceived distinctly if a solid body held in the hand is partially immersed in it. This perception of sonorous vibrations by the sense of touch has given rise to the false notion that other nerves than the auditory nerve are capable of the sensation of sound.

Of the propagation of sound to the ear by different media.

1. *By the air.*—Sounds are most frequently heard through the medium of undulations of the air, whether these are primarily excited in it, or imparted to it by other bodies. Sonorous undulations are communicated to the ear with much greater intensity if originally produced in the air, and not merely conducted by it from other bodies; for, in the transition of sonorous vibrations from other media into air, they suffer a diminution of their force. Hence the feeble sound heard when strings or a tuning-fork vibrate without being connected with a sounding-board, by a bridge or other means; while wind-instruments, in which the air is the original seat of the vibrations, require no sounding-board. The only body which could increase the intensity of sonorous vibrations generated in air would be an insulated mass of the same medium. All solid bodies would contribute but little to the strengthening of the sound, on account of the loss of intensity which the vibrations would suffer in their transition from the air originally sounding to the solid body, and from this again to the air.

On account of the difficulty attending the transition of sonorous undulations from water, as from solid bodies, into the air, a sound pro-

duced in the water, and transmitted to the ear by the atmosphere, is always heard faintly; and, if the direction of the sonorous undulations with regard to the surface of the water and air is very oblique, it is not even audible; just as rays of light under the same conditions do not reach the eye. This difficulty was experienced by M. Colladon in his experiments on the velocity of the propagation of sound in water. A tube immersed in the water and applied to the ear afforded him no aid, until a solid plate for the reception of the sonorous undulations of the water was placed at the lower end of the tube. To render sounds in water distinctly audible while the ear is surrounded by an atmosphere of air, the sonorous undulations must not merely be received by a solid rod and conducted by this to the ear, but this rod must be brought into contact with a solid plug occupying the meatus externus, so that the intervention of air as a conducting medium may be avoided as much as possible. This is the only method by which the full sound of a small bell immersed in water can be made audible.*

The obstruction to the sound is still greater when it has to pass first from air into water, and then again from the water into air, before reaching the organ of hearing; hence persons in the diving-bell hear nothing of sounds generated in the atmosphere above.†

The loudness of sounds heard through the medium of the air is, moreover, influenced by its density and degree of dryness. The velocity of sound increases with the diminution of the density of the air, but its intensity decreases. The sound of a bell vibrating in the exhausted receiver of an air-pump is scarcely audible; though this strictly proves nothing more than that sonorous vibrations are very much diminished in intensity in passing from the bell to the rarefied air, and from this to the walls of the receiver. Scarcely any experiments have been instituted to determine the difference in the impression produced on the ear by undulations of air of very different densities, when these undulations pass immediately to the tympanum, without the intervention of any solid bodies: there is merely the observation of Dr. Saussure, that, in the rarefied stratum of air on the summit of Mont Blanc, the discharge of a pistol caused a sound not louder than that ordinarily produced by a small rocket.

2. Direct propagation of sound to the ear (that is, to the membrana tympani) by water, may be observed in bathing. All sounds generated

* The fact observed by M. Colladon, that the sound of a bell in the water is not transmitted thence to the ear, but that merely a short impulse is perceived, might depend on the distance of the sounding body, or on the imperfect conducting power of the media; for the sound of a bell made to vibrate in water near the ear is, according to my experiments, always heard, unless it has to pass through a stratum of air to reach the labyrinth instead of being conducted by a chain of solid bodies.

† See Gehler's *Physic. Wörterb.* viii. p. 449.

in the water itself are then heard very distinctly. This fact, which was proved by the experiments of Nollet and Monro, is known to every bather. Sounds produced in the air, and merely transmitted from it to the ear by the water, are, on the contrary, not heard well, on account of the considerable diminution of intensity which sonorous undulations undergo in their transition from air to water.

3. Direct propagation of sound to the organ of hearing by solid bodies.—Sonorous undulations, excited primarily in the air, are conducted to the tympanum best by that medium; and, in the same manner, solid bodies form the best conducting medium for sounds emitted by solid bodies. The sound produced by striking a piece of wood or metal is feeble when communicated to the ear by the atmosphere only; while it is very intense if a cord attached to the sounding body is held between the teeth, or brought into contact with both ears previously plugged. Thus Herhold and Rafn were enabled to conduct the sonorous vibrations produced by striking a spoon so perfectly, by means of a cord fixed to it, that at the distance of three hundred yards it still sounded like a bell. All parts of the head, soft or hard, are capable of conducting to the organ of hearing the sonorous vibrations of solid bodies brought into contact with them, but the soft parts less perfectly than the hard.* The sound conducted by a rod which is in contact with the sounding body, is heard most loudly when the rod is applied to the head at parts where the bones are but thinly covered, or, still better, where they are bare, as at the teeth. The ticking of a watch is heard very distinctly when it is made to touch the teeth, particularly those of the upper jaw, from which the sound is conducted to the ear by hard parts only. The sound is fainter when the watch is applied to the tongue, and still more so when it is held free in the cavity of the mouth. The sound of the watch is conducted with equal and even greater intensity to the ear by the solid parietes of the meatus auditorius externus, this passage being stopped, and a rod interposed between the watch and the plug, or the part of the ear very near the plug. The sonorous undulations in this case, instead of being propagated by the bones of the cranium directly to the labyrinth, are conducted by the solid walls of the external auditory passage to the membrana tympani and ossicula auditus. The use of the

* According to the experiments of Perier and Larrey, on persons in whom the trephine had been used, one should believe that sonorous undulations are communicated from the air to the auditory nerves more readily by the mere soft parts than by the cranial bones covered with skin. It is stated that, when the ears of such individuals were stopped, sounds were heard most perfectly if the sounding body was brought over the cicatrix of the part where the cranial bone had been removed. This result, which appears to require confirmation, was obtained, it is said, only when the opening made by the trephine was situated at the fore part of the head.—(Larrey, *Clinique Chirurgicale*; Paris, 1836, p. 33.)

ear-trumpet consists partly in the undulations of the air being conducted to the ear with undiminished intensity, and partly upon the resonance of the column of air contained in the trumpet; but its effect is also increased by the vibrations of the resounding walls of the tube being communicated immediately to the solid parietes of the meatus auditorius. Of this we may easily convince ourselves by holding the ear-trumpet by the side between our teeth while our ears are stopped, and then causing another person to speak into the mouth of the tube: the condensation of the undulations of the air in the tube can here have no influence; and, nevertheless, an extremely loud sound is heard, which is due to the resonance of the tube itself, but which, if conducted to the ear by the atmosphere only, would be scarcely heard.

The immediate propagation of sound by solid parts to the organ of hearing comes into play also when the ear is applied to the surface of the ground for the purpose of listening. The sounds are heard still better if the ear is stopped, and the plug touches the ground. Those sounds only, of course, are heard with any intensity which are either produced primarily in the ground itself, or communicated to it by solid media from other solid bodies in which they were originally generated: thus, the treading of men and horses is heard distinctly; while sounds produced primarily in the air, being with difficulty imparted from it to the solid ground, are not heard well in this manner.

The stethoscope again affords us an example of the propagation of sounds from solids, through other solid bodies, to the solid parts surrounding the organ of hearing. The use of the stethoscope has but little advantage over the application of the bare ear, except as far as the sound is increased in intensity by the resonance of the tube. With its ordinary construction, the stethoscope conducts sounds to the ear in two ways,—namely, by its solid portion, which receives the sonorous undulations from the solid body yielding the sound, and transmits them to the solid parts of the head around the organ of hearing; and by the column of air in its interior, which receives the sounds also from the solid body, but transmits them through the air of the meatus externus to the membrana tympani. The interior column of air is a much less effective conducting medium than the wooden tube around, on account of the difficulty attending the transition of sonorous vibrations from solids to air, but it is of use by its resonance. Hence a simple solid rod does not answer the purpose of a stethoscope. Sounds may be heard, however, very distinctly by means of a mere rod, if the ear be stopped by a plug of chewed paper, and the one end of the rod be applied, not to the plug itself, on account of the sound of friction which would be produced, but to the external ear near it. Here the sonorous undulations are communicated more completely to the walls of the external meatus by means of the plug, and are thence propagated to the membrana tympani.

In cases of deafness, where the undulations of the air do not make sufficient impression even with the aid of an ear-trumpet, it is sometimes of use to convert the undulations of the air into undulations of solid bodies, and conduct these to the organ of hearing by solid media. This is best effected, when the object is to hear the voice of another person, by causing him to direct his voice into a basin, whence it is conducted to the ear by a rod held between the teeth, or applied to a plug inserted into the meatus auditorius of the deaf person.*

3. *Acoustic properties of the labyrinth.*

The fluid of the labyrinth, aquula Cotunnii, or perilymph, first claims our attention as the most general and constant of the acoustic provisions of the labyrinth. In all forms of organs of hearing, the sonorous vibrations affect the auditory nerve through the medium of a fluid. Why is it that nature has, in most animals, provided against the communication of sound to the auditory nerve directly from the bones of the cranium without the intervention of a fluid? In the case of animals living in the air, the reason might be supposed to be, that sonorous undulations are communicated with so much more facility from air to fluids, through the intervention of a tense membrane, which is either in direct contact with the water, or acts on it through the medium of a moveable and insulated solid body, than from air to solid bodies. But this explanation will not apply to aquatic animals: for vibrations are imparted very readily from water to solid bodies, and therefore would be so to the cranial bones, as, for example, in the osseous fishes; and, nevertheless, here also the sonorous vibrations of the cranial bones become undulations of the fluid of the labyrinth before acting on the auditory nerve. There must, therefore, be some more general reason for this provision. It is probably to be found in the following circumstances. The ultimate purpose of the organ of hearing is to impart, as perfectly as possible, the impulses of the sonorous vibrations to the fibres of the auditory nerve. This nerve being soft, and impregnated with water, like all nerves, sonorous undulations, in being communicated to it from solid parts, would be partly converted into undulations of a fluid, before producing their impression on the fibres. Besides, however, the impregnation of the nervous fibres with water, on which their softness depends, all the interspaces between the fibres are, as in all soft tissues, filled with fluid matters, either blood or the fluid of cellular membrane. Hence the auditory nerve, in receiving the sonorous undulations through the medium of the fluid of the labyrinth, receives it from a medium of the same kind as that

* All the experiments of this kind on the hearing of deaf persons by means of solid conductors, are collected in the works of Chladni, (*Akustik*, p. 262. 286,) and Lincke (*op. cit.* p. 530).

which occupies all the porosities and interstices of the nervous fibres themselves. On this account, the vibration of the particles in the nerve itself will probably be much more uniform in character than if merely the surfaces of the nerve had been in contact with solid parts; in which case, the more internal particles of the nerve, being distant from the surface of the solid bone, would be acted on in a different manner from the more superficial particles. Muncke * remarks, with reference to the fluid of the labyrinth, that water, although ill-adapted for the generation of sound, is nevertheless an excellent conductor of it, even a better one than air. This I cannot admit; it can be true only with respect to the velocity of the propagation of sound; for the undulations of air are conducted with least loss of intensity by air, those of water by water.

The passages called aqueducts appear to me to merit no consideration in relation to the physiology of hearing. They contain neither membranous canals nor fluid, nor even venous trunks, but merely serve to bring the periosteum of the cranial bones and dura mater into connexion with the internal periosteum of the labyrinth.†

There are three grades of developement of the labyrinth: 1, a mere vestibule with a sacculus; 2, a vestibule with semicircular canals, and a membranous labyrinth of correspondent form; 3, the preceding parts with the cochlea.

Vestibule, semicircular canals.—The function usually ascribed to the semicircular canals is that which Scarpa attributed to them; namely, the collecting of the sonorous undulations from the bones of the cranium. Canals generally influence sound by the resonance of their contents, by the condensed propagation of the sonorous undulations in their interior, and by the resonance of their walls.

No influence can be attributed to the canals of the labyrinth as resulting from the resonance of their contents; for water bounded by solid bodies is capable of perhaps no perceptible resonance, its undulations not being reflected by its surfaces when thus bounded. Water seems to be little adapted, also, for collecting sonorous undulations from surrounding solid bodies. I poured water into the canals on the surface of a dissecting table, which communicate with each other at several points, and then applied a vibrating tuning-fork to the end of the table, while I immersed a conducting-rod in the water only, and brought its other extremity into contact with my ear; but I did not in this way hear the sound at all more distinctly than when the rod was merely brought into contact with a small quantity of water dropped upon the surface of the table. Again, I caused canals to be bored in a thick plate of wood, and parallel with the surface of the wood, which could be inserted into the side of a wooden bowl, in such a manner that

* Gehler's Physic. Wörterb. iv. 2, p. 1211.

† Müller's Archiv. 1834; p. 22.

the openings of the canals in the wood communicated with the cavity of the bowl. The bowl and canals being now filled with water, and sonorous undulations excited in the water of the bowl by means of the musical pipe covered at its lower extremity with membrane, the sound, conveyed to the ear by a conducting-rod, was as distinct when the openings from the bowl into the canals of the wood were closed with plugs as when they were open.

The extent to which a tube filled with water may be compared to a communicating-pipe filled with air, is the next subject of inquiry. In pipes filled with air, sound may, as is well known, be conveyed to a considerable distance with scarcely any loss of intensity, in consequence of the difficulty with which undulations are communicated from air to the solid walls of the tube, and also owing to their being reflected at the curvatures. It is quite otherwise with a tube filled with water; sonorous undulations are reflected to a certain extent even in water, but the undulations pass into solid bodies much more readily from water than from air, and the strength of an impulse propagated in a determinate direction is maintained in its integrity only for a very short distance when transmitted through a tube filled with water. This may be illustrated by an experiment. The one-foot musical pipe was by its lower extremity, which was covered with membrane, connected with a tube four inches long, and eight lines in diameter, and this tube, and lower end of the pipe, were then immersed in water, which came into contact with the entire surface of the membrane above mentioned; the sound could then be heard, by means of a conducting rod, much louder at the extremity of the tube than elsewhere in the water,—louder than on the exterior of the conducting tube, and than at the same distance from the end of the musical pipe when no tube was subjoined to it. But if the tube was a foot instead of four inches in length, no difference in the intensity of the sound could be detected at the end of the tube, and in the water at other parts of the vessel. Again, I connected two bowls filled with water by means of a glass tube six feet in length, also filled with water, but could not observe any signs of the tube with water exerting a conducting power similar to that of tubes filled with air. A sound excited at one extremity of the tube was not heard with any greater intensity or distinctness in the water at the other extremity, than in the vicinity of the resounding walls of the second bowl.

It may therefore be inferred, that though the semicircular canals have probably in some degree the power of conducting sounds in the direction of their curve, yet this conducting power is in them much less perfect than in tubes containing air. Some slight increase of intensity of the impression on the nerve of hearing, will result from the circumstance that the same undulation which enters one extremity of a semicircular canal from the vestibule will return with a part of its

force by the other extremity. Dr. Young has ascribed some importance to this circumstance.

This degree of reinforcement of the impression of hearing by means of the semicircular canals, will take place even when the impulse is communicated to the labyrinth, not through the fenestræ, but by the cranial bones, as in fishes, and partly in man.

The resonance of the bony walls of the semicircular canals, excited by sonorous undulations in their fluid contents, comes next under consideration. It is found that when sonorous vibrations are imparted to solid surfaces in contact with water, the sound is, *cæteris paribus*, always heard with greater intensity near these surfaces than in other parts of the fluid; in an experiment to verify this fact, the conducting-rod of course must not actually touch the solid surface. If two such resonating surfaces are situated very near to each other, the sonorous undulations of the water between them have necessarily greater intensity. This I had an opportunity of observing in the experiment above mentioned with the piece of wood bored with canals which communicated with the cavity of a basin filled with water. The sound of a tuning-fork applied to the wooden plate was heard rather louder when the conducting-rod was introduced from the basin into the cavity of one of the canals, than when it was held near the walls of the basin at the same distance from the tuning-fork. That the comparison may be accurate, the extent to which the conducting-rod is immersed in the water must in this experiment be always the same; for, the greater the length of rod covered by the water, the louder is the sound.

If, then, we admit that the membranous semicircular canals have the conditions requisite for collecting the sonorous undulations of the cranial bones in their fluid contents, and for conducting them through their curved cavity more readily than they are carried off by the surrounding hard parts in the original direction of the undulations or impulses, the increased intensity of the sonorous vibrations thus attained will be of advantage in acting on the auditory nerve where it is expanded in the ampullæ of the canals, and in the sinus communis. Where the membranous canals are in contact with the solid parietes of the tubes, this action must be much more intense. But the membranous semicircular canals must have a function independent of the surrounding hard parts; for in the *Petromyzon* they are not separately enclosed in solid substance, but lie in one common cavity with the sinus communis, —a fact of great physiological importance.*

Autenrieth and Kerner imagined that the different canals had the

* [Mr. Pilcher (in his work on the Structure and Diseases of the Ear) has collected accounts of numerous cases of congenital deafness, in which malformations of the internal ear, particularly of the semicircular canals, were found to exist.]

power of making us acquainted with the direction whence sound comes. But we do not appear to have any perception of the direction of sound, except as far as we can judge from its acting more strongly on one ear than on the other, or from the difference in its intensity according as the direction of the external ear and concha is varied. Even supposing we were able to distinguish the direction of the impulse of the vibrating particles acting upon our auditory nerve, this direction would always be two-fold; for, after giving the impulse, the particles vibrate in the opposite direction, and this alternation of movement is regularly repeated in the production of a musical sound.

The *otolites* or *calcareous lapilli** found in the labyrinth of fishes and fish-like Amphibia, and the *crystalline pulverulent masses* which supply their place in other animals, would necessarily reinforce the sonorous vibrations by their resonance, even if they did not actually touch the membranes upon which the nerves are expanded; but, inasmuch as these bodies lie in contact with the membranous parts of the labyrinth, they communicate to these membranes and the nerves vibratory impulses of greater intensity than the aquula Cotunnii can impart. Sonorous undulations in water are not perceived by the hand itself immersed in the water, but are felt distinctly through the medium of a rod held in the hand.

This appears to me to be the real office of the lapilli and crystalline pulpy masses in the labyrinth. The opinion that the crystalline particles of these masses are, during the action of sonorous undulations on the ear, thrown off from the internal surface of the membranous labyrinth in the same way that dust or sand is thrown into motion upon vibrating solid laminae and membranes, is not confirmed by experiment; for the dust floating on water does not present the slightest appearance of movement during the passage of sonorous undulations.

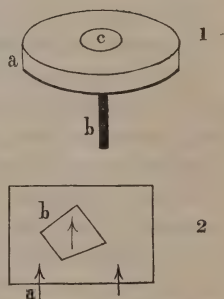
To illustrate further the use of these parts by experiment is difficult. I put some sand and water into a small sac, formed of a portion of softened pig's bladder, pressed this sac flat, and placed it in water, imitating the membranous labyrinth with the crystalline pulverulent mass; I then compared the intensity of the sound of a musical pipe in the water transmitted to the ear by means of a conducting-rod, when the sac with its contents was interposed between the pipe and rod without touching either, and when it was removed: the sound was certainly louder, *cæteris paribus*, when the sac was present. I found,

* The otolites of the osseous fishes have a structure similar to that of the enamel of teeth. Those of the zander (*Perca lucioperca*), for example, are formed of laminae with a zone-like arrangement, in which a regular fibrous structure is at once evident. If laminae of these bodies ground thin be treated with muriatic acid, they are seen to be constituted of acuminate bodies, exactly like those which I have described as existing in the enamel before it has become hardened. (Poggendorf's *Annal.* 38)

however, that the same flattened sac merely filled with water, without any sand, had the same effect of increasing the intensity of the sound (by resonance). On what this resonance of membranes in water depends, I have not satisfied myself. The humerus of a bird, deprived of its earthy matter, when placed in contact both by its outer and inner surface with water, presented scarcely any sign of resonance: the same was the case with a portion of calf's intestine. A sound excited in the water without the sac, and transmitted to the ear by a conducting-rod, had exactly the same intensity, whether the portion of intestine immersed in water to which the rod was applied was long or short, provided the distance of the rod from the point of origin of the sound was the same.

The cochlea.—In investigating the acoustic properties of the labyrinth, it becomes necessary that we should inquire the direction in which impulses and undulations are propagated in the solid parts and fluid of the apparatus. Savart's investigations relative to the propagation of impulses from solid bodies to water, and from water to solid bodies, from which he obtained the result that impulses are communicated from one of these media to the other, without any change of direction, afford us data for this inquiry. If, to the bottom of a

Fig. 135.



vessel filled with water, *a*, (fig. 135, 1,) a rod, *b*, is fixed, longitudinal vibrations excited in this rod are transmitted through the water to a lamina of wood, *c*, floating upon its surface, without change of direction, as is proved by the movement of the particles of sand strewed upon the surface of the lamina *c*. Again, if vibrations are excited by means of a violin bow in a vessel filled with water, *a*, (fig. 135, 2,) and they have the direction indicated by the arrows, they are propagated in the same direction through the water, and also through a lamina of wood, *b*, floating upon its surface, of which the margins are directed obliquely with regard to the sides of the vessel and to the direction of the undulations; the oblique direction of the borders of the plate with relation to the impulse does not modify the direction in which it is propagated. In both these cases, then, the sonorous vibrations are propagated in the same direction as if in the one instance the rod *b* were connected immediately with the plate *c*, and as if in the second the side of the vessel *a* were connected with the plate *b*, which is placed perpendicularly to it, by a solid conducting medium. Hence we may apply the laws of the propagation of impulses through plates united to each other at right angles to the case of the labyrinth.

We have already shown (page 1255) that when undulations are com-

municated to laminae united at right angles, and their direction in the plate *a* (fig. 136) is that indicated by the arrows, they are also propagated through the perpendicular plate *b d*, and the second horizontal plate *c c'*, in the same direction. Now, the perpendicular plate *b d*, in this experiment, may be compared to the modiolus of the cochlea, and the horizontal plates to the lamina spiralis of the same part, and the resemblance becomes more evident when the figure is modified, as in fig. 137. In whatever direction, therefore, sonorous undulations are ex-

Fig. 136.

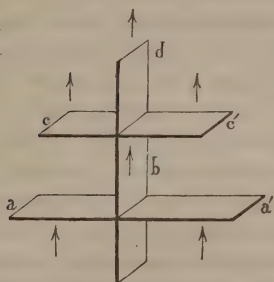
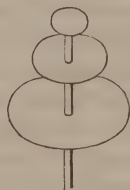


Fig. 137.



cited, either in the modiolus, or in the spiral lamina, they will be propagated with the same direction through all parts of the cochlea, whether the impulse be communicated primarily from the cranial bones to the modiolus, or to the external wall of the cochlea, and thence to the spiral lamina, or from the fluid of the labyrinth to either of these parts. With respect to the undulations communicated to the cochlea through the medium of the fluid of the labyrinth, it is to be observed, that the direction of the fenestra ovalis is such, that a line perpendicular to its area would be nearly parallel to the modiolus of the cochlea; consequently, impulses originating at this fenestra will probably excite in the solid parts of the cochlea undulations having the same direction as the modiolus,—that is to say, the lamina spiralis will in its whole extent become the seat of vibrations having a direction nearly perpendicular to its surface. I am able to ascertain easily the direction of an impulse in solid plates which communicate sound to each other in water by means of a conducting-rod, the sound being always heard with greatest intensity when the rod is applied to the plate in the direction in which the impulse travels.

Thus far we have supposed the different parts of the cochlea to be affected by the impulse simultaneously, or nearly so. The question now suggests itself, whether the sonorous pulses may not possibly be propagated gradually along the windings of the cochlea, for example, from the fenestra rotunda to the cupola, either through the medium of the fluid occupying the scalæ, or by following the turns of the lamina spiralis.

lis itself. Since the winding canal of the cochlea and the lamina spiralis are of considerable length, namely, from eighteen to nineteen lines at the outer border of their convolutions, the use of the cochlea—if such a successive propagation of the impulses along its windings were possible—might be to prolong the impression of sounds. The truth of this hypothesis is, however, very doubtful. Sounds would certainly be conducted in that manner through a winding-tube filled with air; but sonorous undulations or impulses are communicated so readily from water to solid bodies, that they will not be propagated simply along the windings of a canal filled with water, but will be transmitted from the commencement of the spire, through the modiolus, so as to intersect the canal at another part of its convolutions. The spiral lamina also can scarcely be supposed to conduct sound merely in the course of its windings; for, being continuous with the solid exterior parietes of the cochlea, and with the modiolus, it will communicate the vibrations to them as readily as to the prolongation of itself, and the impulses thus imparted to the modiolus and walls of the cochlea will be transmitted to other parts of the spiral lamina, without regularly following its windings. A regular propagation of the sonorous undulations along its course would require that the canal, instead of being spirally convoluted, were extended in a straight line in the direction of the impulse.

It is certain, therefore, that this hypothesis of the undisturbed progression of the impulse along the water of the scalæ, or in the spiral lamina, is untenable. Such a gradual affection of the nervous fibres along a course more than $1\frac{1}{2}$ inch in length, would also rather diminish than increase the distinctness of perception; for along the tract there would at the same time be particles of the nerve affected by the maximum of the impulse and the succeeding rarefaction, while in others the maximum could not yet be attained, so that the effect of echo would be produced. The cochlea, however, instead of giving rise to this inconvenience, really provides against its occurrence by the winding of its canal being confined within a small space.

The spiral lamina of the cochlea must therefore be regarded as a surface upon which all the fibres of the cochlear nerve are spread out, so as to be nearly simultaneously exposed to the impulse of the sonorous undulation, and simultaneously thrown into the maximum state of condensation, and again into the maximum state of rarefaction. According to this view of the use of the cochlea, it would make no essential difference if the nervous fibres were spread out upon several distinct circular plates surrounding the modiolus, instead of a continuous spirally wound lamina; but the latter form employed by nature has this advantage, that all parts of the spiral lamina are so connected with each other, that an impulse to one part is communicated more readily to the others.

The convoluted form of the cochlea serves also the purpose of affording in a small space a considerable extent of surface required for the expansion of the nervous fibres.

The object which nature has sought to attain in the cochlea seems to be the spreading out of the nervous fibres upon a solid lamina which should communicate with the solid walls of the labyrinth and cranium, at the same time that it is in contact with the fluid of the labyrinth; and which, besides exposing the nervous fibres to the influence of sonorous undulations by two media, should be itself insulated by fluid on either side. In accordance with this view, we can explain all the acoustic provisions of the cochlea.

The connexion of the lamina spiralis with the solid walls of the labyrinth adapts the cochlea for the perception of the sonorous undulations propagated by the solid parts of the head and the walls of the labyrinth. This use of the cochlea has been previously pointed out by Professor E. H. Weber.* The membranous labyrinth of the vestibule and semi-circular canals is suspended free in the liquor Cotunnii, and is evidently destined more particularly for the perception of sounds through the medium of that fluid, whether the sonorous undulations are imparted to the fluid by the intervention of the cranial bones as in fishes and in man, when sounding bodies are brought into communication with his head or teeth, or through the fenestræ. The membranous labyrinth is certainly exposed to the influence of the resonance of the bony parietes of the labyrinthine cavity; for sonorous undulations in water are, as I have shown, heard with greatest intensity in the vicinity of solid walls; but yet it remains strictly true that the membranous labyrinth is acted on immediately only by the undulations of a fluid. The spiral lamina on which the nervous fibres are expanded in the cochlea is, on the contrary, continuous with the solid walls of the labyrinth, and receives directly from them the impulses which they transmit. This is an important advantage; for the impulses imparted by solid bodies have, *cæteris paribus*, a greater absolute intensity than those communicated by water.

The greater intensity of the undulations of solid bodies than of liquids, has been sufficiently proved in the course of the preceding inquiries. If it be wished to compare the intensity of the sonorous impulses imparted by solid bodies and by water, the experiment must not be performed by placing the conductor in the one case directly in contact with the solid body, and in the other in the water; it will not thus yield a fair result; for the undulations of solid bodies are communicated without any loss of intensity to other solid bodies in contact with them, while in their transition from water to a solid body undulations lose much of their force: but if the conductor be placed in the water,

* Annot. Anatomicae et Physiologicae. Lips. 1834

not in contact with the solid body, but very near it, and again in the water at a distance from it, but at the same distance from the source of the sound, the conditions for the comparison are the same in both cases. The undulations are then in both instances undulations of water before they are communicated to the conducting-rod. And thus it is found that, even when a sound is excited in the water, the sonorous undulations are more intense in the water near the surface of the vessel containing it than in other parts of the water equally distant from the point of origin of the sound; hence we may conclude that, *cæteris paribus*, the sonorous undulations of solid bodies act with greater intensity than those of water. Hence we perceive at once an important use of the cochlea.

This is not, however, the sole office of the cochlea; the spiral lamina, as well as the membranous labyrinth, receives sonorous impulses through the medium of the fluid of the labyrinth from the cavity of the vestibule and from the fenestra rotunda. The lamina spiralis of man and Mammalia is indeed much better calculated to render the action of these undulations upon the auditory nerve efficient than the membranous labyrinth; for, as a solid body insulated by a different medium, it is capable of resonance. That this is the case, may be rendered evident by experiment. A thin lamina of wood tightly fixed in the interior of a thick wooden bowl filled with water increases by resonance the intensity of sonorous undulations excited in the water more than the thick walls of the bowl. The musical pipe closed at its lower extremity with membrane being sounded in the water while directed perpendicularly against the firmly fixed lamina of wood, but without touching it, the conducting-rod placed near the lamina at all parts of it, even at a distance from the source of the sonorous undulations, conveys to the ear a loud sound. If the pipe is directed towards the inner surface of the bowl, and at the same distance from it as it was before from the lamina of wood, the sound is heard distinctly by means of a conductor placed in the water near the walls of the bowl, but it is not so loud as in the former case. It is immaterial whether the lamina be fixed at one edge or both, provided its surfaces be free and in contact with the water.

Lastly, it may be observed that the object of the fibres of the nerve being spread out singly upon the lamina spiralis is evident. In the first place, it insures a more complete participation of the fibres in the impulses communicated by the solid parts of the cochlea; and, secondly, the intensity with which the sonorous undulations are communicated to a body is proportionate to the extent of surface over which they can act on it. Thus, when a sound is excited in water, and is conducted to the stopped ears by means of a rod, the intensity of the sound heard increases with the depth to which the rod is immersed in the water, or with the extent in which it is in contact with the surface of the water.

CHAPTER III.

OF THE ACTION OF SONOROUS UNDULATIONS UPON THE AUDITORY NERVE,
AND OF THE ACTIONS OF THIS NERVE ITSELF.1. *Mode of action of sonorous undulations upon the auditory nerve.*

THE investigation of this part of our subject must be based on a knowledge of the properties of the undulations which reach the fluid of the labyrinth.

The distinct properties of the undulations excited by a sounding body, and propagated to the labyrinth, are:—

1. Their thickness or length, and the duration of their impression.
2. Their breadth.
3. Their intensity, or the extent through which the particles affected by them vibrate.

The *thickness or length* of an undulation is its extent in the direction in which it is moving. The length of the undulation in any conducting medium is regulated partly by the time occupied in the production of one entire vibration by the sounding body, and partly by the conducting power of the medium. The column of air of the 32-feet organ-pipe performs 32 double vibrations, or gives 16 impulses in one direction in the course of a second. One part of the double vibration produces the condensation of the medium, analogous to the elevations of the wave on the surface of water; the other returning part of the vibration produces the rarefaction of the medium, or the depression of the wave. Now, since the velocity of sound in the air is about 1022 feet in a second [1124 feet English measure, at 62° Fabr.], the distance between the commencement and termination of one undulation, or its length, in the air, will be $\frac{1022}{16}$, or about 64 feet, when the musical value of the sound is that of the lowest C of the organ produced by the 32-feet pipe.

The fundamental note of the 16-feet organ-pipe, C¹, is produced by 64 half vibrations, or 32 pulses; and the length of corresponding undulations in the air is $\frac{1022}{32}$, or nearly 32 feet.

The length of each of the 64 undulations which, occurring within the space of a second, produce the note C² of the 8-feet organ-pipe, is in the air $\frac{1022}{64}$, or nearly 16 feet.

The length of the waves in the air for the note C³ is eight feet; for the note C⁴, two feet; and for C⁵, one foot.

The velocity of sound in water is four times greater than in air, being as much as 4090 feet in a second [4708 English feet, according to M. Colladon's experiments]. The length of the undulations in water is therefore greater in the same proportion: thus, the length of the undulations for the lowest C of the organ, that of the 32-feet pipe, is 256

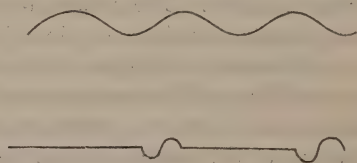
feet; for C^1 , 128 feet; for C^2 , 64 feet; for C^3 , 32 feet; for C^4 , 16 feet; for C^5 , 8 feet; and for C^6 , 4 feet. Such is the length of the undulations, therefore, which traverse the fluid of the labyrinth; and we may hence perceive that, even in the production of the highest notes, several undulations cannot occupy the small space of the labyrinth at the same time, but rather that, as a general rule, the summit or most condensed part of one wave will have left the labyrinth before the most condensed part of a second wave reaches it.

The duration of the impression which an undulation produces in its passage through any one particle of the labyrinth depends on the duration of each vibration of the body emitting the sound; for the lowest C of the organ, the duration of each vibration is $\frac{1}{16}$ of a second; for C^6 , $\frac{1}{1024}$ of a second.

It becomes necessary in some instances to distinguish between the length of undulations and their distance from each other. If the sound is generated by a body vibrating to and fro, the distance between the undulations is 0; they succeed each other uninterruptedly, as is represented in the upper line of fig. 138, where the curves must be supposed to have the place of con-

densations and rarefactions. But if the sound is excited by impulses between which moments of repose occur, the conducting medium will have returned to a state of rest after the passage

Fig. 138.



of one undulation, before a second undulation reaches the same point, as is represented in the lower line, fig. 138. This mode of succession of sonorous undulations can be produced by means of the toothed wheel used by M. Savart, and by the siren. It appears then, that, under certain conditions, the duration of the impression, or the period occupied by the transition of the separate undulations through a given point of the labyrinth, may be shorter than the interval between the passage of the *maxima* of two undulations.

Throughout the whole length of each wave, from its commencement to its end, the degree of condensation presents different gradations. The condensation gradually increases up to the end of the first fourth, when it arrives at its maximum; towards the middle of its length the density diminishes again. The latter half of the undulation is the seat of the rarefaction; here the particles previously compressed together repel, and strive to separate from, each other. The rarefaction increases as far as the commencement of the last fourth, and then decreases.

During the transition of the sonorous undulation through the fluid of the labyrinth, all the particles of this fluid in succession must pass through these grades of condensation and rarefaction.

The condensation in an undulation being dependent on the greater approximation of the molecules; the rarefaction, on their repulsion or greater separation from each other; all the particles in the wave will simultaneously move through a certain extent of the course of the impulse. The extent of the motion of the particles is at the commencement of the undulation slight; for, the more distant the particles lie from the immediate seat of the impulse, the less is their motion. In the posterior part of the undulation the particles move in the retrograde direction; and in the extent of their motion there is the same difference. During the passage of the undulation through a given point of the medium, the particles occupying this point become affected with an increasing, then with a diminishing state of condensation, and lastly, in the posterior half of the wave, with a state of rarefaction. The velocity also with which particles of the medium at this point are moved, becomes successively greater, reaches its maximum, and then becomes again retarded. During the passage of the posterior half of the undulation through this same point, the particles in their returning vibration move first with increasing, and then with diminishing velocity. All this is capable of application to the action of undulations on the auditory nerve.

The length of the undulations remains the same, whatever their distance from the source of the sound; but the extent of oscillation of the particles affected by them diminishes in a direct ratio with the square of the distance. It is, however, on the extent of oscillation of the particles that the intensity or loudness of the sound depends.

The undulations in air extend in a spherical form; a portion only of this sphere, however, which may be called the breadth or superficial extent of the undulations, strikes the ear. The breadth of the undulation employed in hearing depends on the extent to which the auditory nerve is acted on by it. Those undulations which enter the labyrinth from the tympanum have only the superficial extent of the fenestræ, ovalis and rotunda; but from these points they spread themselves out in the fluid of the labyrinth.

2. *Of the distinction of different sounds.*

A single impulse communicated to the auditory nerve seems to be sufficient to excite the sensation of sound; of this we have an example in the sound produced by an explosion or the sudden division of the air, by the coming together of two previously separated bodies of air, as in cracking a whip, &c. There is at all events nothing to refute this opinion, and M. Chladni is inclined to adopt it; although it must be admitted that a single shock to the air will very readily excite a succes-

sion of undulations. Most frequently, certainly, several undulations or impulses on the nerve concur in the production of the impression of sound. But it may be asked whether each of the impulses, a series of which produce a given sound, must not itself be of such intensity that it would singly excite the sensation of the auditory nerve; and whether a succession of impulses, so feeble that each alone would produce no impression upon the sense of hearing, would not be inaudible. The solution of this question has not hitherto been attempted, and it does not at present seem possible.

By the rapid succession of several impulses at unequal intervals a noise or rattle is produced; from a rapid succession of several impulses at equal intervals, a musical sound results, the height or acuteness of which increases with the number of the impulses communicated to the ear within a given time. This admits of demonstration by means of the siren of M. Cagniard La Tour, or of the toothed wheel of M. Savart. A sound of definite musical value is also produced when each of the impulses, succeeding each other thus at regular intervals, is itself compounded of several undulations, in such a way that it would alone give the impression of an unmusical sound; that is to say, by a sufficiently rapid succession of short unmusical sounds at regular intervals a musical sound is generated. This is, in fact, exactly what takes place in the use of the above-mentioned instruments. Each individual impulse which they produce is a compound unmusical sound, which is readily distinguished, even while, by the quick succession of several such sounds, the impression of a musical note of definite pitch is produced.

The number of successive impulses required to produce a definite note is the next point of inquiry. It would appear, from M. Savart's researches, that two impulses which are equivalent to four single or half vibrations are sufficient. The note produced by the shocks of the teeth of a revolving wheel at regular intervals upon a solid body is still heard when the teeth of the wheel are removed in succession until two only are left; the sound produced by the impulses of these two teeth has still the same definite value in the scale of music. If a wheel with two thousand teeth, and revolving once in a second, is deprived of its teeth in half its circumference, so that only one thousand teeth are left, the length of the intervals between the impulses produced by these remaining teeth remains of course the same; but all the teeth, except two contiguous to each other, may be removed, and the sound resulting from the successive strokes of these two teeth, if the rate of revolution of the wheel be the same, namely, once in a second, will still be capable of comparison with the note of a musical instrument, so that its value may be determined.

If, however, only one tooth be left on the wheel, the definite musical note will no longer be heard, but only a rattling noise produced by the

strokes of the single tooth, unless the wheel be made to revolve so rapidly that the interval between the separate strokes of the tooth is not greater than is required to elapse between the successive impulses for the production of a determinate note.

Where sounds are excited by vibrations or undulations, of which, when one has ceased, the next immediately commences, it may be matter of doubt whether the pitch of the resulting note may not depend on the length or some other property of the individual undulations. But experiments with the toothed wheel have shown that the acuteness or pitch of musical notes is not in any way dependent on the nature of the undulations; for, in the case of the different notes produced by the revolving wheel, the separate impulses which the solid body struck by the teeth of the wheel imparts to the air are constantly the same, whether the wheel revolves quickly or slowly; it is only the length of the intervals between them which varies.

The maximum and minimum of the intervals of successive pulses still appreciable by the ear as determinate sounds, have also been determined by M. Savart, more satisfactorily and more accurately than had previously been done. If their intensity is sufficiently great, sounds are still audible which result from the succession of 48,000 half vibrations, or 24,000 impulses, in a second; and this, probably, is not the extreme limit in acuteness of sounds perceptible by the ear. Again, the sound resulting from thirty-two half vibrations, or sixteen impulses, in a second, is not, as has been supposed, the lowest appreciable note; on the contrary, M. Savart has succeeded in rendering sounds audible which were produced by only fourteen or eighteen half vibrations, or seven or eight impulses, in a second; and sounds still deeper might probably be heard if the individual pulses could be sufficiently prolonged. For the duration which an impulse must have in order to be heard is shorter in proportion to the height or acuteness of the note produced, the interval between every two impulses becoming less in proportion as the notes are higher in the scale: in the deeper notes, therefore, the duration of the impulses must be longer in proportion to the depth of the note. To give a greater duration to the impulses in very deep notes, M. Savart made use of a wheel with two or four free spokes or bars, which during the revolution of the wheel passed close to the edge of a thin board, without touching it, and, by the compression and rarefaction of the air thus induced, gave rise to single audible pulses. The succession of these pulses with sufficient rapidity afforded the impression of a deep note. The apparatus was furnished with a register, by means of which the rate of revolution could be accurately ascertained.

By removing one or several teeth from the toothed wheel before mentioned, M. Savart was also enabled to satisfy himself of the fact, that in the case of the auditory nerve, as in the nerve of vision, the

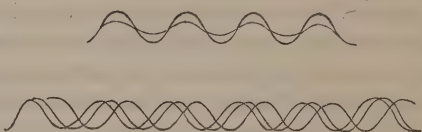
duration of the sensation is longer than that of the impression which causes it; for the removal of a tooth from the wheel produced no interruption of the sound. The gradual cessation of the sensation of sound renders it difficult, however, to determine its exact duration beyond that of the impression of the sonorous pulses.*

3. *Of the simultaneous impression of several different sounds.*

The simplest case of this kind is that where two sounds in unison with each other are heard at the same time. Here the intervals of the pulses are equal; while the maxima of the undulations may or may not be coincident. In the first case, the condensations of the undulations and the impulses are increased in intensity, as represented in the upper figure (fig. 139); in

Fig. 139.

the second, the maxima of the two or more unisonant series of vibrations follow each other, as in the lower figure, so as to form a compound series of which the aliquot portions are similar,



and the intervals equal. This can in no way disturb the impression on the ear. The accompanying figures may also serve to represent the combination of undulations resulting from resonance with the undulations of the primary sound, since they, like two or more unisons, are equal in their number and intervals. "Timbre" or tone results from the decussation of the waves which determine the height of the sound with other accessory waves. These figures (fig. 139) may illustrate also the change in the "tone" or "timbre" of an instrument produced by resonance. The slightest change in the conditions of a resounding body causes an alteration of tone probably by influencing the order in which the undulations are thrown off from it. Since, therefore, the mode of decussation of the primary undulations with those due to resonance may be extremely various, the varieties of tone resulting must also be very numerous.

The perception of two sounds falling simultaneously on the ear, of which the number of the vibrations is different, must be attended with more difficulty than the perception of a single sound; for the circumstance of the maxima of the one series of vibrations intervening between those of the other must render the comparison of their intervals less easy. If, for example, two sounds, *a* and *b*, (fig. 140,) with the intervals marked by the dots, fall simultaneously on the ear, a compound series, as at *c*, will be produced. If the two sounds in such a case are

* Ann. de Chimie et de Physique, xliv. 337; xlvii. 69.—Poggendorf's Annal. xx. 290.—Fechner's Report, i. 335.

excited by two wheels with similarly formed teeth, the separate pulses individually must all be similar; and the nature of the impulses, therefore, cannot be the cause of the two sounds

Fig. 140.



being distinguished from each other, which nevertheless is possible, as I have satisfied myself by experiment. The discrimination of the sounds must, therefore, be due to the perception of the intervals of each in the compound series of pulses. In distinguishing the undulations *a* from the undulations *b*, though the two series are intermingled, the ear must recognise the constant recurrence of the maxima of each series after certain intervals. To the smaller intervals resulting from the intervention of the maxima of one series between those of the other the attention is not directed owing to their not returning regularly, and being very dissimilar according to their position. This discriminating power of the sense of hearing is analogous to the faculty of vision, by virtue of which different parts of a complicated figure are in turn seen with greater distinctness than the rest (see page 1179); for, in the same way, we are able to distinguish the separate tones of one instrument amongst those of an entire orchestra. This power is, of course, much facilitated by the circumstance of different instruments having different tones; the principal vibrations of the sounds of each being attended by other accessory vibrations.

Fig. 141.



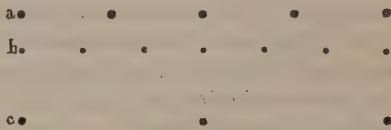
Great interest attaches to the case where two bodies giving sound simultaneously are nearly, but not quite, in unison; one vibrating, for example, one hundred times, the other one hundred and one times in a second. Here the vibrations or pulses of the one sound gradually gain on those of the other (see fig. 141), with which they become coincident again at the end of every second. The maxima of the undulations in the two series will be furthest removed from each other at the middle of each second, the maximum of the one being then, in fact, coincident with the minimum of the other, so that each is destroyed; but at the end of each second the maxima will coincide, and form one wave of double intensity. From the commencement to the middle of each second the intensity of the sound will diminish, because thus far the maxima of the one series of undulations will tend more and more to coincide with the minima of the other series of undulations (see fig. 141), until they quite neutralize each other:

but from that point the maxima of the one series of undulations will become more and more distant from the minima of the other, and the sound will proportionally increase in loudness, until at the termination of the second it will be doubly as loud as would be produced by either series separately, the maxima of their undulations here coinciding. At the middle point of each second there should be a moment of complete absence of sound. No such interruption of the sound, however, is heard, but merely a greater faintness of the sound at that point of time; we may, therefore, regard this as a new proof that sensations of the auditory nerves are of longer duration than the action of the exciting cause. The alternate decrease and increase of intensity of the sound when two instruments nearly, but not entirely, in unison, are vibrating simultaneously, are called "beats." The phenomenon is easily produced by striking two musical strings which are not quite in unison.

When two sounds, of which the vibrations stand in a simple ratio to each other, as of 2 to 3, 3 to 4, or 4 to 5, and in which the coincidence of two impulses or undulations recurs with sufficient frequency, a third sound is produced by this coincidence of the undulations of the two sounds at regular intervals. If, for example, in one sound, *a*, (fig. 142,) two vi-

Fig. 142.

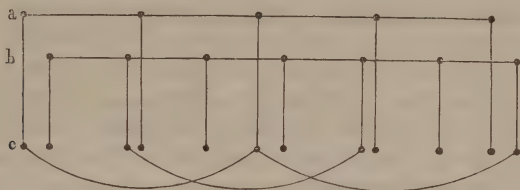
brations are produced, while three are taking place in the other, *b*, a coincidence of their vibrations will occur at every second undulation of the one and at



every third of the other, provided they have originally commenced at the same moment; and this return of undulations of double intensity, *c*, at regular though longer intervals, will give rise to a new sound which was first observed by the celebrated musician Tartini. It must be remarked that the dots in the figure do not represent the pulses themselves, but merely their maxima, and that intermediate between them the minima, or points of greatest rarefaction, must be imagined to be situated. The third note resulting from the coincidence of certain vibrations of two other notes may be produced by means of strings as well as by pipes, provided the primary sounds be sufficiently intense and prolonged. If the D string of a violin be tuned to E, and sounded by a long stroke of the bow together with the A string, the lower octave of A is heard. If the C of the A string be sounded with the E above it, the lower octave of C is heard as a third sound: if the first B above the lines be struck with the D above it, G of the second octave below them is heard also. Under certain circumstances, as might be expected, and as M. Blein has observed, two additional sounds are heard.

In the foregoing instance it was presupposed that the first pulse of the two sounds occurred at the same moment. But this may not be the case; and then, instead of a perfect coincidence of the undulations, there will be only an approximation to coincidence at certain intervals, as in figure 143, where the series of sonorous pulses *a* and *b* have the

Fig. 143.



same relation to each other as in the former figure; that is to say, two pulses occur in *a* in the space of time occupied by three in *b*. They give rise to the compound series of pulses *c*, in which the approximation to coincidence of the maxima of the two series of pulses at certain intervals is sufficient to be perceived, and to give rise to the accessory note; although this will not be so loud and distinct as in the former case. The greater the approximation to coincidence of the maxima of the two series of pulses or undulations, the louder and more distinct will be the new note produced. From this consideration we may infer the cause of the uncertainty in the occurrence of this phenomenon, and the reason why it can never be calculated on in music.

The accessory sounds of Tartini thus produced, which are always deeper than the primary notes, must be distinguished from the higher accidental notes of strings, bells, &c. which are sometimes heard associated with the fundamental tone, and which belong to the system of harmonics. The latter have a physical cause in the action of the instrument itself; the former have not.

Of the harmony of sounds.—The relation which the notes of the scale of music universally adopted bear to each other, is determined partly by the degree in which the power of discriminating the general impressions produced by different numbers of vibrations is possessed by the sense of hearing, and partly by the circumstance that a pleasing effect is produced upon the sense by the succession of sounds of which the vibrations bear a simple numerical relation to each other.

The ratio most easily recognised by the ear is that of 1 : 2 : 4 : 8, &c. that, namely, of the fundamental note to its octaves. Sounds, of which the vibrations in the same period are in the proportion of 1 to 2, are so similar that they act on the ear only as repetitions of one another; hence the relation between two sounds is not essentially altered by rais-

ing or lowering one of them the extent of one or two octaves. Other proportions which are easily recognisable, and agreeable to the ear, are that of 2 to 3, or of the fundamental note to the "fifth;" and that of 4 to 5, or of the fundamental note to the "third." If the fundamental note be designated as 4, the proportional number for the "third" will be 5, that for the "fifth" 6, and that for the octave 8. Or, taking the fundamental note C at 1, the relative numbers for the vibrations of the "third," "fifth," and "octave" will be as follows :

C	E	G	C ¹
1	$\frac{4}{3}$	$\frac{3}{2}$	2
Fund. note.	Third.	Fifth.	Octave.

These four notes together form the simplest and most effective combination of sounds: the first three constitute a triad, or chord of three notes, which is very agreeable to the ear. Music has, however, not stopped here; there are, as might readily be conceived, other intervals which are capable of being combined so as to produce an agreeable impression on the sense of hearing. The sound to which the octave 2 would stand in the ratio of a "fifth," or of 3 to 2, bears an equally simple proportion to the fundamental note, namely that of $\frac{4}{3}$ to 1; it is the note F of the musical scale. The "third" of the note G again, or B, bears the proportion of $\frac{1}{5}$ to the fundamental note, this being 1. Further, between C and E lies another note, which stands in the relation of a "fifth" to the G of the lower octave, and bears the proportion of $\frac{9}{8}$ to the fundamental note C, or 1; it is named D. Lastly, there is between G and B a note which bears the same proportion in the number of vibrations to B, as C does to D; it is A, the proportional number of which, compared with the fundamental note, is $\frac{1}{5}$.

Thus we have the musical scale :

C,	D,	E,	F,	G,	A,	B,	C ¹ .
1,	$\frac{9}{8}$,	$\frac{5}{4}$,	$\frac{4}{3}$,	$\frac{3}{2}$,	$\frac{5}{3}$,	$\frac{1}{5}$,	2.

The relation of the different notes in this series to each other is as follows :

C, D,	= 1 : $\frac{9}{8}$
D, E,	= 1 : $\frac{1}{9}$
E, F,	= 1 : $\frac{1}{15}$
F, G,	= 1 : $\frac{9}{8}$
G, A,	= 1 : $\frac{1}{9}$
A, B,	= 1 : $\frac{9}{8}$
B, C ¹	= 1 : $\frac{1}{5}$

The intervals 1 : $\frac{9}{8}$ and 1 : $\frac{1}{9}$ are called entire tones; the interval 1 : $\frac{1}{15}$, a semitone. Where notes are separated by an entire tone, we distinguish other intermediate sounds or semitones.

It will be perceived that the raising of one note a semitone, or the interval of 1 : $\frac{1}{15}$, is not identical with the lowering of the following note the same extent; C# is therefore a different sound from D $\flat$. The in-

terval $1 : \frac{5}{4}$, or $C : E$, is called the major third; the interval $1 : \frac{6}{5}$, or $C : E\flat$ the minor third.

To form a harmonious combination of several sounds, or a chord, it is necessary that the different sounds should bear a simple relation to the fundamental note, and also to each other. The notes C, E, G , produce a harmonious triad, or chord of three; for the number of the vibrations of E and G , as compared with C , is in the ratio of 5 to 4, and of 3 to 2; and E and G themselves also are concords, their proportions being as 1 to $\frac{6}{5}$. The notes $C, E\flat, E\sharp$, on the contrary, of which the ratio is $1 : \frac{6}{5} : \frac{5}{4}$, do not form a chord. For though C with $E\flat$, and C with $E\sharp$, are concords, the combination of $E\flat$ with $E\sharp$ is discordant, their ratio being as $\frac{6}{5} : \frac{5}{4}$, or as $1 : \frac{2}{2}\frac{5}{4}$. The cause of harmony is, therefore, the simple relation between the sounds in regard to the number of their vibrations.

The combination of the fundamental note with the major third and the fifth,—namely, C, E, G , of which the ratio is $1 : \frac{5}{4} : \frac{3}{2}$,—is called the perfect major chord; the combination of the fundamental note with the minor third and the fifth, or $C, E\flat$, and G , of which the ratio is $1 : \frac{6}{5} : \frac{3}{2}$, is called the perfect minor chord. They both consist of the intervals of a major third and a minor third, namely, $\frac{5}{4}$ and $\frac{6}{5}$, which together form a fifth. In the perfect major chord the major third precedes the minor; in the perfect minor chord the minor third precedes the major. These two chords produce different impressions on the ear. The harmony is more pleasing in the major chord.

Discords also are rendered agreeable to the ear when they form the transition to concords, by which the dissonance is resolved. A dissonant chord contains, besides concordant intervals, an additional discord. Thus, the octave would be concordant with the fundamental note, the third, and the fifth; but the seventh forms a discord. The chord of the seventh is formed by the combination of the fundamental note with the third, fifth, and seventh; it is a dissonant chord. A dissonance is resolved by a concord which contains a concordant in place of the discordant note, or which forms a concord with this note. This neutralization of discords is similar to the effect which the intervention of a third colour between two disharmonious colours, with one of which it harmonizes, while towards the other it is indifferent, has in removing the impression of the want of harmony. Thus the want of harmony between blue and red is removed by the intervention of green, which harmonizes with red, and is indifferent towards blue. Orange has the same effect, it being the complementary colour of blue, and indifferent towards red. The influence of discords as well as concords upon the sense of hearing has been very well set forth by Descartes in the passage pointed out by Chladni: “*Inter objecta sensus illud non animo gratissimum est, quod facillè sensu percipitur, neque etiam facillimè; sed quod non tam*

facile, ut naturale desiderium, quo sensus feruntur in objecta, planè non impleat; neque etiam tam difficulter ut sensus fatiget." The harmony of octaves is too simple to be pleasing; and even dissonance becomes pleasing when the difficulty attending the perception of the discordant intervals is relieved by a succeeding concord.

In a long succession of notes the relation of the intervals cannot be preserved in arithmetical perfection, such as is otherwise required by the ear, as is shown by the following example adduced by Chladni. When the intervals G, C, F, D, G, C, are executed continuously and accurately, the C, when it occurs the second time, will not have the same value as at first; and the same is the case with the G. The accurate ratio of the notes or the intervals is as follows:

$$G : C = 3 : 2$$

$$C : F = 3 : 4$$

$$F : D = 6 : 5$$

$$D : G = 3 : 4$$

$$G : C = 3 : 2;$$

or the relation of the notes in the series $G : C : F : D : G : C = 243 : 162 : 216 : 180 : 240 : 160$. G, therefore, has at first the value 243; the second time, 240: C values the first time 162; the second time, 160. If further repeated, the notes would vary more and more from their original value. This inconvenience is remedied by giving to them such a slight deviation from their true ratio, as is not perceptible to the ear; this is called "temperament." When the deviation from the true musical ratio is distributed equally among all the notes, the "temperament" is "even;" when unequally, it is "uneven." The first has been found the most generally applicable in music; while the attempt to maintain certain notes in the different octaves in theoretical purity has only rendered the other notes more imperfect. The defects in the intervals incident to the even temperament are not perceptible by the ear, any more than other slight deviations from the accurate tuning of an instrument. If the ear detected such small deviations from the true musical intervals, the attainment of these intervals upon instruments would be impossible; since, as it is, the perfect tuning of an instrument for practical purposes is attended with very great difficulty.*

Influence of the mind in hearing.—The perception of the direction of sounds is not a faculty of the sense of hearing itself, but is an act of judgment which founds it on experience previously acquired. From the modifications which the sensation of sound undergoes according to the direction in which the sound reaches us, the mind infers the position of the sounding body. The only true guide for this inference is the

* Full information with regard to the musical intervals will be found in Chladni's *Akustik*.

more intense action of the sound upon one than upon the other ear. But even here there is room for much deception by the influence of reflexion, or resonance, and by the propagation of sound from a distance without loss of intensity through curved conducting-tubes filled with air. By means of such tubes, or of solid conductors which convey the sonorous vibrations from their source to a distant resonant body, sounds may be made to originate apparently in a new situation.

The direction of sound may also be judged of by means of one ear only; the position of the ear and head being varied, so that the sonorous undulations at one moment fall upon the ear in a perpendicular direction, at another moment obliquely.

When neither of these circumstances can guide us in distinguishing the direction of sound, as when it falls equally upon both ears, its source being, for example, either directly in front or behind us, it becomes impossible to determine whence the sound comes: this, which has been demonstrated by Venturini's experiments,* is a necessary consequence of physical laws. Undulations give not merely the impulses of condensation in one direction, but that of rarefaction in the opposite; and, when several undulations succeed one another, these impulses in opposite directions regularly alternate. If, therefore, the nerves were capable of distinguishing the direction of impulses, no means would thus be afforded for determining whether a sound came in one direction or in the opposite.

Ventriloquists take advantage of the difficulty with which the direction of sounds is recognised, and also of the influence of the imagination over our judgment, when they direct their voice in a certain direction, and at the same time pretend themselves to hear the sounds coming from thence.

The distance of the source of sounds is not recognised by the sense itself, but it is inferred from their intensity. The sound itself is always seated but in one place, namely, in our ear; but it is interpreted as coming from an exterior soniferous body. When the intensity of the voice is modified in imitation of the effect of distance, it excites the idea of its originating at a distance; and this also is taken advantage of by ventriloquists.

The mind has, however, the power of influencing the act of sensation itself,—of voluntarily increasing its intensity, as in “listening.” By the faculty of attention we can distinguish one sound out of several or many others,—can follow the tones of one instrument in a full orchestra.

When two persons address their speech to our opposite ears simultaneously, the two impressions conveyed to the sensorium become mixed; and it is only by great exertion of the attention, and by the aid of a dif-

* Voigt's Magazin, Bd. 2.

ference of tone of the two voices, that we are enabled to follow the sounds of one exclusively, disregarding those of the other, which are then heard as a more or less indistinct murmur. When the activity of the sensorium is not directed to the impressions communicated to it by the auditory nerves, sounds that exist are not heard ; or, what frequently happens, a sound may be so faint, that, on account of the mind being directed to other objects, it is for a moment disregarded, but is heard as soon as the attention is recalled to it. Similar phenomena are observed to occur in the case of the other senses.

Permanence of the sensation of sound.—The experiments of Savart, already referred to (see page 1299), prove that the effect of the action of sonorous undulations upon the nerve of hearing endures somewhat longer than the period during which the undulations are passing through the ear. If, however, the impression of the same sound be very long continued, or constantly repeated for a long time, then the sensation produced may continue for a very long time, more than twelve or twenty-four hours even, after the original cause of the sound has ceased. This must have been experienced by every one who has travelled several days continuously in a heavy public vehicle, for some time after which the rattling noises are heard when the ear is not acted on by other sounds.

We have here a proof that the perception of sound as sound, is not essentially connected with the existence of undulatory pulses ; and that the sensation of sound is a state of the auditory nerve, which, though it may be excited by a succession of impulses, may also be produced by other causes. The sensations of the retina remaining after the external impression of light had ceased, have been attributed by some persons to a retention of some of the matter of light for a certain time by the retina, as in the absorption of light by dark bodies ; but, in the case of the sense of hearing, such an hypothesis is evidently untenable. No irritating matter and no impulse can be here retained ; and, even if it be supposed that undulations excited by the impulse are kept up in the auditory nerve for a certain time, they must be undulations of the nervous principle itself, which, being excited, continue until the equilibrium is restored.

Double hearing.—Corresponding to the double vision of the same object with the two eyes, is the double hearing with the two ears ; and analogous to the double vision with one eye, dependent on unequal refraction, is the double hearing of a single sound with one ear, owing to the sound coming to the ear through media of unequal conducting power. The first kind of double hearing is very rare ; instances of it are recorded, however, by Sauvages and Itard. In one of the two cases related by Sauvages, the octave was heard with the fundamental note, which, if the observation was correct, would be difficult to explain. In

Itard's case, the sound heard by the two ears differed in height. Such cases may possibly be found to be more frequent than is supposed, when attention is more directed to the subject: I was myself once troubled by a kind of echo of higher pitch which accompanied sounds of moderate intensity, such as the human voice. This phenomenon was, however, very transient, and has never recurred; moreover, I do not know that it arose from unequal action of the two ears.

The second kind of double hearing, which depends on the unequal conducting power of two media through which the same sound is transmitted to the ear, may easily be experienced. If a small bell be sounded in water, while the ears are closed by plugs and a solid conductor is interposed between the water and the ear, two sounds will be heard differing in intensity and tone; one being conveyed to the ear through the medium of the atmosphere, the other through the conducting-rod. In like manner, if, while both ears are plugged, the pipe closed by membrane at its lower extremity be dipped into the water and sounded by another person, its note may be propagated to the ear with two different characters at the same time, by the atmospheric air, and by the solid rod immersed in the water.

Acuteness of hearing.—The sense of vision may vary in its degree of perfection as regards either the faculty of adjustment to different distances, the power of distinguishing accurately the particles of the retina affected, sensibility to light and darkness, or the perception of the different shades of colours. In the sense of hearing there is no parallel to the faculty by which the eye is accommodated to distance, nor to the perception of the particular part of the nerve affected; but just as one person sees distinctly only in a bright light, and another only in a moderate light, so in different individuals the sense of hearing is more perfect for sounds of different pitch: and just as a person, whose vision for the forms of objects, &c. is acute, nevertheless distinguishes colours with difficulty, and has no perception of the harmony and disharmony of colours, so one, whose hearing is good as far as regards the sensibility to feeble sounds, is sometimes deficient in the power of recognising the musical relation of sounds, and in the sense of harmony and discord; while another individual, whose hearing is in other respects imperfect, has these endowments.

Many persons, whose hearing is good, are incapable of perceiving very high or acute tones; Dr. Wollaston observed several instances of this kind: while deaf persons sometimes hear shrill sounds very well. Among the causes of this latter condition is, as we have before remarked, a state of too great tension of the membrana tympani, in whatever way produced. Many deaf people hear sounds, which are not very intense, better when a loud noise prevails at the same time. Of this condition, *paracusis Willisiana*, two instances are described by Willis:

one was that of a person who could only maintain a conversation when a drum was beat near him; in the other case, the individual could hear only while a bell was ringing. Similar cases have been observed by Holder, Bachmann, and Fielitz;* they are, perhaps, to be attributed to a state of torpor of the auditory nerve, which requires to be roused before it can exercise its functions. Sometimes, however, the circumstance of a deaf person hearing particular sounds during a great noise as well as other people who are not deaf, may arise from his being much less disturbed by the noise than they. It is thus that the deaf person mentioned at page 1261 explains the fact that, when travelling in a closed carriage, he can take a part very well in conversation. His companions, he says, do not then hear each other's voices better than he, because the noise of the carriage is heard much more loudly by them. Excessive acuteness of hearing, *hyperacusis*, arises from a state of too great excitability of the auditory nerve, and corresponds to the photophobia of vision.

The causes on which the defect of a musical ear depends, are unknown. A person who is deficient in the sense of musical intervals, harmonies, and discords, will be a bad singer, though he have a good voice.

Subjective sounds—sounds independent of sonorous vibrations.—These are the result of a state of irritation or excitement of the auditory nerve produced by other causes than sonorous impulses. A state of excitement of this nerve, however induced, gives rise to the sensation of sound. Hence the ringing and buzzing in the ears heard by persons of irritable and exhausted nervous system, and by patients with cerebral disease, or disease of the auditory nerve itself; hence also the noise in the ears heard for some time after a long journey in a rattling noisy vehicle. Ritter found that electricity also excites a sound in the ears (see page 1063). From the above truly subjective sounds we must distinguish those dependent, not on a state of the auditory nerve itself merely, but on sonorous vibrations excited in the auditory apparatus. Such are buzzing sounds attendant on vascular congestion of the head and ear, or on aneurismal dilatation of the vessels. Frequently, even the simple pulsatory circulation of the blood in the ear is heard. To the sounds of this class belong also the snapping sound in the ear produced by a voluntary effort, and the buzz or hum heard during the contraction of the palatine muscles in the act of yawning; when air is forced into the tympanum, so as to make tense the membrana tympani; and in the act of blowing the nose, as well as during the forcible depression of the lower jaw.

The buzzing in the ears which attends obstruction of the Eustachian tube does not at present admit of a satisfactory explanation.

In Dr. Henle the peculiar circumstance presents itself, that gently

* See Muncke, in Gehler's *Physic. Wörterbuch*, iv. 2, p. 1220.

passing the finger over the cheek excites a sound in the ear. This may be owing to a reflex transmission of the impression made upon the facial nerve to the acoustic nerve through the medium of the brain, or it may be produced by a movement of the muscles of the ossicula auditus excited by reflex nervous action.

Sympathies of the auditory nerve.—Irritation or excitement of the auditory nerve is capable of giving rise to movements in the body, and to sensations in other organs of sense. In both cases it is probable that the laws of reflection through the medium of the brain come into play. An intense and sudden noise excites in every person closure of the eyelids, and in nervous individuals a start of the whole body. The secondary sensations induced by impressions on the sense of hearing are principally seated in the nerves of touch, or common sensation. A sudden noise excites in persons of excitable nervous system an unpleasant sensation, like that produced by an electric shock, throughout the body, and sometimes a particular feeling in the external ear. Various kinds of sounds, such as the friction of paper, or scratching of glass, cause in many people a disagreeable feeling in the teeth, or, indeed, a sensation of cold trickling through the body. Intense sounds are said to make the saliva collect in the mouth in some people.*

The sense of hearing may in its turn be affected by impressions on many other parts of the body; but this is observed especially in diseases of abdominal viscera, and in febrile affections. Here, also, it is probable that the central organs of the nervous system are the media through which the impression is transmitted.

The cases in which sensitive impressions of other kinds affect the sense of hearing by sympathy are very rare. The observation of Dr. Henle, related above, affords an instance of such sympathy. It has been maintained by many writers that even the nerves of touch are capable of audition, or at least of affording a very easy path for the transmission of the sonorous undulations to the seat of the sense of hearing. That they have such a conducting power is by no means probable; but that an impression on a nerve of touch may by reflection exert an influence upon the auditory nerve is very likely, since a similar relation of mutual action is observed to exist between other senses; and an impression on the nerve of hearing itself is capable of exciting sensations in the nerves of touch. But the instances in which an impression on the latter nerve excites the sensibility of the auditory nerve are extremely rare.

The chorda tympani and nervus facialis have no share in the sense of hearing, and are incapable of influencing it, except by such a reflex action as we last referred to.

* Many other examples of sympathy of this kind have been collected by Tiedemann, (*Zeitschrift f. Physiol.* B. i. H. 2,) and Lincke (*op. cit.* p. 567).

SECTION III.

Of the sense of Smell.

CHAPTER I.

OF THE PHYSICAL CONDITIONS FOR THE PERCEPTION OF ODOURS.

THE sense of smell ordinarily requires for its excitement to a state of activity the action of external matters, which produce certain changes in the olfactory nerve; and this nerve, like that of taste, is susceptible of an infinite variety of states dependent on the nature of the external stimulus.

The first condition essential to the sense of smell is the existence of a special nerve, the changes in whose condition are perceived as sensations of odour; for no other nerve is capable of these sensations, even though acted on by the same causes. The same substance which excites the sensation of smell in the olfactory nerves causes a peculiar taste in the nerve of taste, and may produce an acrid and burning sensation in the nerves of touch. The opinion of Kant, that smell is distant taste, appears to me to be incorrect.

The second condition of smell is a peculiar condition of the olfactory nerve, or a peculiar change produced in it by the stimulus or odorous substance.

The material causes of odours are, in the case of animals living in the air, substances suspended in a state of extremely fine division in the atmosphere; or gaseous exhalations, often of so subtile a nature that they can be detected by no other re-agent than the sense of smell itself. In fishes the odorous matters are contained in the water; but in what form, —whether dissolved in the same manner as the gases absorbed by water,—is uncertain. The solution of these matters in water is clearly no reason for denying the sense of smell to fishes, or for placing the sense of taste in their nares; for the essential characteristic of the sense of smell consists, not in the gaseous nature of the odours, but in the special sensibility of certain nerves, and in its difference from the sensibility with which the nerves of taste are endued. The matters of odours, also, must in all cases be dissolved in the mucus of the mucous membrane before they can affect the olfactory nerves, and their state in the mucus must be the same as that in which they are contained in water. On the other hand, the nerve of taste is not acted on solely by liquid and solid matters; gaseous substances also are sometimes tasted when, like sulphurous acid, and many other gaseous bodies, they are capable of being dissolved in the fluid covering the tongue. It may, therefore, be easily conceived that the very same principle will produce

different sensations in the organs of smell and taste; in the former the sensation of a particular odour, in the latter that of a peculiar taste. The observation of Treviranus, that in animals living in the air the organ of smell is comparable to a lung, in fishes to a gill or branchia, is, to a certain extent, correct and ingenious; but it would be as erroneous to suppose that the odorous matters dissolved in water must be converted into the gaseous state before acting on the olfactory nerve, as that the gases absorbed and dissolved in the water must be restored to the form of gases in the branchiæ before being taken up into the blood. The state in which these gases are contained in the blood is, indeed, the same as that in which they exist in the water. Lastly, it is to be observed that the olfactory nerves of fishes are identical with the olfactory nerves of all other animals; they arise from the same parts of the brain, the lobi olfactorii, which, even in Mammalia, exist in the form of the olfactory bulb.

A further condition necessary for the perception of odours is, that the mucous membrane of the nasal cavity be moist; for, as we have already observed, the moisture of the mucous surface is the vehicle through the medium of which the odorous matters are more immediately applied to the nerves. When the Schneiderian membrane is dry, the sense of smell is lost; thus, in the first stage of catarrh, when the secretion of mucus within the nostrils is lessened, the faculty of perceiving odours is either lost, or rendered very imperfect.

In animals living in the air, it is also requisite that the odorous matters should be transmitted in a current through the nostrils. This is effected by the respiratory movements: hence we have voluntary influence over the sense of smell; for by interrupting respiration we prevent the perception of odours, and by repeated inspirations render their impression more intense.

In aquatic animals this influence over the sense by voluntary movement does not exist; for in them the nostrils are generally closed posteriorly, and do not communicate directly with the respiratory organs. Yet even here the effect which the current through the nostrils would produce is attained in another way,—namely, by the constant current into the mouth, and from the branchial apertures, which is maintained by the movements of the branchial operculum.

CHAPTER II.

OF THE ORGAN OF SMELL.

THE organ of smell is but little known in invertebrate animals, though the perception of odours is very acute in many of them, as in the common meat or blue fly (*Musca vomitoria*), which deposits its ova in

putrefying animal substances, and is sometimes deceived by the odour of the *Stapelia hirsuta*.*

The principle determining the form of the organ of smell, and its varieties, is that of obtaining a large sentient surface within a small space. In this respect the organ of smell, and respiratory organs, are much allied.

In fishes, and, as Rusconi has shown, in the *Proteus* among the Amphibia, the increase of surface is attained by means of folds of mucous membrane, which either are arranged side by side, as in the *Cyclostomata* (Lamprey, Myxine, &c.); radiate from a central point, as in the Sturgeon; or project as parallel laminæ from the two sides of a median band. The laminæ are frequently subdivided, in a tuft-like or arborescent form.

In most fishes the nasal cavities are superficial depressions, not extending through the palate. In the *Lophius piscatorius* they are bell-shaped organs, supported upon a pedicle, and having folds of membrane at the fundus of their cavity. In the *Cyclostomata* the nasal cavities are united into one, from which a tubular canal extends to the surface of the head, as in the *Petromyzon* and *Ammocætes*; or to the extremity of the muzzle, as in the *Myxine*. This nasal tube is, in the myxinoid fishes, very long, and provided with cartilaginous rings just like the trachea. In the cyclostomatous fishes the nasal cavity is not a blind sac; a canal extends from it, at least, through the bony palate. In the *Petromyzon*, however, there is no opening in the soft palate; the palatine canal from the nasal cavity ends as a blind tube between the bones of the cranium and the membrane lining the cavity of the fauces. In the *Ammocætes*, also, the palatine nasal canal terminates by a cæcal extremity. It serves, therefore, in these fishes merely to give the power of forcing water out of the nasal cavity, and of taking fresh water in. In the myxinoid *Cyclostomata*, on the contrary, both the soft and hard palate are pierced by the nasal tube; and behind its palatine opening there is merely a membranous valve directed backwards, which appears to serve the purpose of keeping in motion and renewing the water contained in the nasal cavity.

The apparatus for forcing the water out of the nasal cavity in the *Petromyzon*, and the moveable valve in the myxinoid fishes, seem to be provisions rendered necessary by the organization of these animals. A necessary condition for the perception of odours is the movement of the medium in contact with the sentient surface. In man it is necessary that a current of air should be maintained through his nose. In most aquatic animals the renewal of the strata of the odoriferous medium around the head is attained by the respiratory movements, which pro-

* The different facts which have been observed relative to the sense of smell in the *Articulata* will be found in Wagner's *Vergleichende Anatomie*, 1834; B. i. p. 467.

duce an inward current at the oral aperture, and an outward one at the branchial clefts. But in the cyclostomatous fishes the renewal of the fluid in the nostrils cannot be effected in this manner while their mouth is used in suction.

In reptiles and Amphibia the nasal cavity is always perforate. In some of the Proteidea the palatine extremity of the nasal canal does not pass through the bones, but merely through the upper lip, in consequence of the rudimentary condition of the superior maxillary bone, which lies free in the soft parts: this is, however, not a general character of the Proteidea, for in the Axolotl the palatine opening of the nares is bounded by bone, as in other Amphibia. The *Proteus* has, also, plicæ of the mucous membrane in the nasal cavity, like those in the nasal cavity of fishes; in the other genera of the Proteidea these plicæ are absent.

In reptiles and birds the turbinated processes for the increase of surface first make their appearance.

In Mammalia the nasal apparatus includes the labyrinth of the ethmoid bone, the turbinated bones, and the accessory sinuses opening into the nasal cavity. The developement of surface in the inferior turbinated bone is very remarkable. The most peculiar forms are presented on the one hand by the Ruminantia, Solidungula, &c.; on the other, by the Carnivora. In the former orders, the inferior turbinate bone is, at its line of attachment, a simple lamina, which afterwards divides into an upper and a lower lamella, of which the first is rolled upwards like a scroll of paper, the other downwards in the same form. In Carnivora the lamina divides into branches, which give off side branches much in the manner of the arbor vitæ of the cerebellum. Compared with these states of developement, the condition of the turbinated bones in the human subject appears quite rudimentary. The organs discovered by Stenson maintain a communication between the nasal cavity and mouth at the situation of the foramen incisivum in many Mammalia. These canals must not be confounded with the partly membranous, partly cartilaginous, tube observed by Jacobson, which lies on the floor of the nostrils, between the vomer and the mucous membrane, and communicates with the canals of Stenson. The function of these parts is not known.*

The accessory cavities or sinuses communicating with the nostrils seem to have no relation to the sense of smell. Air impregnated with the vapour of camphor was injected by Deschamps into the frontal sinus through a fistulous opening, and Richerand injected odorous substances into the antrum of Highmore; but in neither case was any odour perceived by the patient. Nature seems to attain nearly the same object

* See Rosenthal in Tiedemann's *Zeitschrift f. Physiol.* ii. p. 289. With reference to the pretended absence of olfactory nerves in the Cetacea, see page 767.

whether she fills the cavities of bones with air or with fat; in either way she renders the bones lighter than they would be were they solid throughout. In birds many bones are filled with air; those of the trunk through the medium of the lungs, those of the head through the Eustachian tube: in man certain bones of the head only contain air, namely, the mastoid process of the temporal bone, and the bones bounding the nasal cavity. The mucous membrane both of the nares, and of the sinuses opening into them, presents the ciliary motion in all animals.

The process by which the stimulus is conveyed to the nerve, in the senses hitherto considered so complex, is here very simple. The odorous matters suspended in the air in the form of vapour, or sometimes, perhaps, of a very fine powder, are brought into contact with the sentient mucous surfaces by the current to which the respiratory movements give rise. A current of air from within outwards sometimes excites the sensation of odour, as in the case of odorous substances being developed in the respiratory organs, or when such matters developed in the digestive organs are expelled upwards by eructation.

It only remains for us here to consider the mode in which the perception of odours may be rendered more acute or prevented. We are able to avoid the perception of unpleasant odours, by interrupting inspiration through the nose. By inspiring the odorous vapours through the nostrils with greater force, or by repeating the inspiration frequently, we can render their impression greater. In tracking by the scent, animals seek the part of the atmosphere containing the odorous matters by making rapidly-repeated inspirations in different directions, and then follow the scent to its source by the same means. The perception of the odorous matters also may be favoured by the wind. In this way ruminant animals, without tracking the scent, are believed frequently to perceive odours developed at a distance.

Besides the sense of smell, the nasal cavities are also endowed with common sensibility by the nasal twigs of the first and second divisions of the fifth nerve. Hence the sensations of cold, heat, itching, tickling, and pain; and the sensation of tension or pressure in the nostrils. That these nerves cannot perform the function of the olfactory nerves is proved by the cases in which the sense of smell is lost; while the mucous membrane of the nose remains susceptible of the various modifications of common sensation or touch. (See the observations on this subject at page 768.) It is often difficult to distinguish the sensation of smell from that of mere feeling, and to ascertain what belongs to each separately. This is the case particularly with the sensations excited in the nose by acrid vapours, as of ammonia, horse-radish, and mustard, &c. which resemble much the sensations of the nerves of touch; and the difficulty is the more apparent when it is remembered that these acrid vapours have nearly the same action upon the mucous membrane of the eyelids.

CHAPTER III.

OF THE ACTION OF THE OLFACTORY NERVES.

ANIMALS do not all equally perceive the same odours; the odours perceived by a herbivorous animal and by a carnivorous animal are different. The cause of this difference must lie in the endowments of the central parts of the olfactory apparatus. The Carnivora have the power of detecting most accurately by the smell the special peculiarities of animal matters, and of tracking other animals by the scent; but have apparently no sensibility to the odours of plants and flowers. Man is far inferior to carnivorous animals in respect of the acuteness of smell, but his sphere of susceptibility to odours is more uniform and extended.

Opposed to the sensation of an agreeable odour is that of a disagreeable or disgusting odour, which corresponds to the sensations of pain, dazzling and disharmony of colours, and dissonance, in the other senses. The cause of this difference in the effect of different odours is unknown; but thus much is certain, that odours are pleasant or offensive in a relative sense only, for many animals pass their existence in the midst of odours which to us are highly disagreeable. A great difference in this respect is, indeed, observed amongst men. Many odours generally thought agreeable are to some persons intolerable: the smell of burnt horn is to many persons unpleasant; to others, who are not at all fanciful, agreeable. To many individuals *mignonette* does not smell very sweet; but rather herb-like, as Blumenbach observes, and as I experience in my own person. We have no exact proof that a relation of harmony and disharmony exists between odours as between colours and sounds; though it is probable that such is the case, since it certainly is with regard to the sense of taste. It is also not certain that sensations of odours continue after the impression of the odorous matter has ceased, though we can scarcely imagine that such is not the case. It is difficult to ascertain this point by direct observation: the cadaverous odour, which is frequently retained in the nose very long after post-mortem examinations, cannot be regarded as a proof, since it probably arises from some of the odorous matter remaining dissolved in the mucus of the nostrils.

The sensations of the olfactory nerves, independent of the external application of odorous substances, have hitherto been little studied. It has been found that solutions of inodorous substances, such as salts, excite no sensation of odour when injected into the nostrils. The friction of the electrical machine is, however, known to produce a smell like that of phosphorus. Ritter, too, has observed, that when galvanism is applied to the organ of smell, besides the impulse to sneeze,

and the tickling sensation, a smell like that of ammonia was excited by the negative pole, and an acid odour by the positive pole ; whichever of these sensations was produced, it remained constant as long as the circle was closed, and changed to the other at the moment of the circle being opened. Frequently a person smells something which is not present, and which other persons cannot smell ; this is very frequent with nervous people, but it occasionally happens to every one. In a man who was constantly conscious of a bad odour, the arachnoid was found after death, by MM. Cullerier and Maignault, to be beset with deposits of bone ; and in the middle of the cerebral hemispheres were scrofulous cysts in the state of suppuration. Dubois was acquainted with a man who, ever after a fall from his horse, which occurred several years before his death, believed that he smelt a bad odour.

Whether substances which have a strong odour would, when introduced into the circulation, excite the olfactory nerve to the perception of the odour, has not been ascertained experimentally.

No senses are so intimately connected with the instinctive operations of the animal economy, as are smell and taste. Odours excite powerfully the sexual impulse of animals, and, by their influence on the brain and spinal cord, give rise to the actions connected with that impulse.*

SECTION IV.

Of the sense of Taste.

CHAPTER I.

OF THE PHYSICAL CONDITIONS FOR TASTE.

THE conditions for the perception of taste are :—1, the presence of the nerve with special endowments ; 2, the irritation of this nerve by the sapid matters ; 3, the solution of these matters in the secretions of the organ of taste. The mode of action of the substances which excite taste can hardly be mechanical, any more than that of odorous matters ; but must rather consist in the production of a change in the internal condition or material composition of the nerve by matters in solution ; and, according to the difference of these matters, an infinite variety of changes of condition, and consequently of tastes, may be induced in the nerve. It cannot, however, be affirmed that the excitement of taste by a mechanical impression on the nerve of taste is absolutely impossible.

Pressure, traction, pricking, and friction excite in the tongue only varieties of common sensation, it is true ; but Henle has observed that

* An account of the facts known with regard to the sense of smell was published by H. Cloquet at Paris, in 1821, under the title of "*Osphresiology*."

a small current of air directed upon the tongue gives rise to a cool saline taste, like that of saltpetre, and the mechanical irritation of the fauces and palate produces the sensation of nausea, which has no affinity to the various modifications of touch or common sensation, but is so allied to taste that it cannot be separated from it.* Electricity is the only imponderable principle which excites taste.

As a general rule, the matters to be tasted must either be in solution or be soluble in the moisture covering the tongue; insoluble substances produce merely sensations of touch. It is a matter of doubt whether the mere contact of a moist animal substance used as food with the vital organ of taste can excite its specific sensation independently of the matters contained in solution within the mass of food. Some gases, however, as sulphurous acid gas, are capable of exciting the sense of taste.

For a perfect action of a sapid, as of an odorous substance, it is necessary that the sentient surface should be moist. There are no other means for conducting the stimulus to the nerve in this sense than the mucous secretion of the tongue. Hence the investigation here, as in the case of the sense of smell, is rendered very simple.

CHAPTER II.

OF THE ORGAN OF TASTE.

THE sense of taste has its seat in the fauces, but more especially in the tongue, which, nevertheless, is in many animals more important as an organ of deglutition. On account of this latter circumstance, the numerous varieties of form presented by the tongue in the animal series have little interest with reference to the sense of taste, and need not here engage our attention. The circumstance of the tongue being devoid of soft parts and stiff, as in fishes and many birds, (the parrots, ducks, geese, and some other birds are excepted,) must not lead us to infer that the sense of taste is absent; for this sense is a property of the whole fauces,—not of a special limited organ, but of the mucous membrane lining the cavity just mentioned. It is only where animals swallow their prey entire and covered with hair and feathers, as is the case with serpents, that the sensation of taste may be supposed not to exist; the mode in which the food is taken itself rendering taste impossible. The same may be said with regard to the insectivorous and granivorous birds. The peculiar organ in the palate of the *Cyprinus* family which was regarded by many as an organ of taste, has been

* [The translator has shown, at page 1062, that a distinct sensation of taste, similar to that caused by electricity, may be produced by a mechanical stimulus applied to the papillæ of the tongue.]

shown by M. E. H. Weber to be a contractile organ, and is, in my opinion, destined to aid deglutition.

In man, the contact of the finger or any solid body with the soft palate excites the sensation of nausea, which might certainly be explained by supposing it to result from the impression being reflected upon the nerves of taste; but the sensibility of the palate to sapid substances is proved by the experiments of Dumas, Autenrieth, Horn, Lenhossec, Treviranus, and Bischoff; and, when I rub upon the velum palati a small piece of Swiss cheese, I perceive distinctly its taste in the palate. It has been demonstrated by the experiments of Dupuytren, Mayo, and myself, that the ninth, or hypoglossal, is the motor nerve of the tongue, and the lingual branch of the fifth the sensitive nerve; for these experiments have proved that irritating the hypoglossal nerve by galvanism, or mechanically, excites muscular contractions in the tongue, while division of the lingual nerve gives rise to violent pain. Experiments made to ascertain whether the lingual branch of the fifth nerve has any motor power require to be performed with the same precautions as experiments upon the roots of the spinal nerves. The nerve must first be divided, and the peripheral portion thus cut off from its communication with the central organs of the nervous system alone irritated. If the lingual branch of the fifth nerve be subjected to irritation, while yet in connexion with the brain and spinal cord, muscular contractions may be excited in the tongue and other parts by reflection, as I have myself once recently observed.

With respect to the controversy as to whether the lingual branch of the fifth, or the glossopharyngeal, nerve be the nerve of taste; we have already stated the principal arguments (see page 769).* Professor R. Wagner† has adopted Panizza's view, on the ground of physiological as well as anatomical facts; Valentin and Bruns also have arrived at a similar conclusion from the results of their experiments; while those of Kornfeld, Gurlt, and myself favour the opposite opinion,—namely, that the lingual branch of the fifth is the principal nerve of taste.‡ I cannot regard Valentin's experiments as conclusive proofs of the sense of taste residing in the glossopharyngeal nerve, since a fortnight after the division of the nerve the animal is stated to have begun to taste again. This period is so short as even to render it probable that taste was never lost. Dr. Alcock's experiments§ have not decided the question. The perception of bitter substances was [not] lost after division of the glossopharyngeal nerve; it was lost at the anterior part of the tongue only, when the lingual nerve was divided. He believes the sense of

* See also Bischoff, in the *Encyclop. Wörterbuch der Med. Wissenschaft*.

† Froriep's *Notiz*. 1837, n. 75.

‡ See Müller's *Archiv*. 1838, p. cxxxiv; and Valentin's *Report*, 1837, p. 221.

§ *Med. Gaz*, 1836, Nov.; and *Dublin*, vol. x. p. 260.

taste to be seated not only in the glossopharyngeal nerve and the lingual branch of the fifth, but also in the palatine branches of the fifth; the experiments with respect to the latter nerves were not decisive.

The pathological observations, showing loss of taste accompanying lesion of the fifth nerve, as in the cases detailed by Parry, Bishop, and Romberg, are very important. In Mr. Bishop's case, the pressure of a swelling upon the divisions of the fifth nerve was productive of loss of taste in the corresponding half of the tongue.* The case related by M. Romberg† is that of a person in whom taste and common sensibility were lost in one half of the tongue; and here, also, the commencement of the third branch of the fifth nerve was found acted on by a small tumour, while the glossopharyngeal nerve was healthy.

It appears to me certain, both from the experiments of Magendie, Gurlt, Kornfeld, and myself, as well as from the pathological observations of Parry, Bishop, and Romberg, that the lingual branch of the fifth is the principal nerve of taste of the tongue; but I do not regard it as proved that the glossopharyngeal nerve has no share in the perception of taste at the posterior part of the tongue and in the fauces. M. Romberg ascribes to it the sense of nausea, by which the entrance into the digestive organs is guarded.

CHAPTER III.

OF THE SENSATIONS OF TASTE AND THE ACTIONS OF THE GUSTATORY NERVES.

It is quite impossible to explain the various sensations of taste. The nature of the essential quality of taste, by which it is distinguished from smell, common sensation, sight, and the sensation of sound, is, like the nature of every other sensation, quite inexplicable. Of the essential quality of blue, for example, we can form no further conception; it can only be perceived as a sensation; and we must remain contented with the knowledge that the different nerves of sense enjoy special properties, one perceiving colours,—blue, for example; another sounds, a third odours, and so on. But the causes on which the differences in the various sensations of one and the same nerve depend may possibly be ascertained, and in the cases of vision and hearing they are already known. We know that one sound differs from another in proportion to the difference in the number of undulations producing them; and that the number of undulations of the imponderable ether of light, within a given time, is different for each colour. In the cases of the senses of taste and smell, however, we are far from having such a

* *Med. Gaz.* 1833; and *Müller's Archiv.* 1834, p. 132.

† *Müller's Archiv.* 1838; Heft iii.

theory to explain the varieties of sensations. Bellini tried to elucidate the great variety in the sensations of taste by means of the old hypothesis of the different form of the ultimate molecules of bodies,—a theory which cannot be refuted, but which is quite as incapable of proof. At the period when everything was accounted for by chemical polarities, it was customary to make application of this hypothesis also to explain the phenomena of taste.

Besides the sense of taste, the tongue is endued with a very delicate and accurate touch which renders it sensible of the impressions of heat and cold, itching, pain, and mechanical pressure, and consequently of the form of surfaces.

The tongue may lose its common sensibility, and still retain the sense of taste, and *vice versâ*.* This fact renders it probable that the nervous conductors for these two different sensations are distinct, just as the nerves for smell and common sensibility in the nostrils are distinct. It will be easily conceived that the same nervous trunk may contain fibres differing very essentially in their specific properties. Facts detailed at a previous page prove that the lingual branch of the fifth nerve is the seat of sensations of taste; but it is also certain, from the marked manifestations of pain to which its division in animals gives rise, that it is a nerve of common sensibility. The hypoglossal, or ninth nerve, also is endowed with sensibility in addition to its motor power (see page 657).

Many substances having odour as well as taste, their simultaneous action upon the two senses gives rise to a more or less mixed sensation. The sensation of taste may, however, in such a case be isolated from that of smell by closing the nostrils. Many fine wines lose much of their apparent excellence if the nostrils are held close while they are drunk.

It would appear, from the experiments of Horn,† that some substances excite a different taste, according as they are applied to different papillæ of the tongue; an observation which would seem to afford an explanation of the difference often perceived between the flavour first excited by some substances, and those which they leave behind them upon the tongue. Horn instituted experiments with a great number of substances, and found that a part of them tasted the same in all regions of the tongue's surface; while others had very different tastes, according as they were applied in the neighbourhood of the papillæ filiformes, or of the papillæ vallatæ.

Very distinct sensations of taste are frequently left after the substances which excited them have ceased to act on the nerve; and such sensations often endure for a long time, and modify the taste of other

* Müller's Archiv. 1835, p. 139.—Medical Gazette, Oct. 1834.

† Über den Geschmacks-sinn des Menschen. Heidelberg, 1835.

substances applied to the tongue afterwards. After I have chewed a piece of the root of sweet flag (*acorus calamus*), milk and coffee have to me a sourish taste; the taste of sweet substances spoils the flavour of wine, the taste of cheese improves it. There appears, therefore, to exist the same relation between tastes as between colours, of which those that are opposed or complementary render each other more vivid, though no general principles governing this relation have been discovered in the case of tastes. In the art of cooking, however, attention has at all times been paid to the consonance or harmony of flavours in their combination or order of succession, just as in painting and music the fundamental principles of harmony have been employed empirically while the theoretical laws were unknown.

Frequent and continued repetition of the same taste renders the perception of it less and less distinct, in the same way that a colour becomes more and more dull and indistinct, the longer the eye is fixed upon it. Red and white wine can at first be distinguished by their flavour when the eyes are bound; but, after frequently tasting first one and then the other, it soon becomes impossible to discriminate between them.

The simple contact of a sapid substance with the surface of the gustatory organ gives rise frequently to a very indistinct sensation of taste, and sometimes to none at all. The sensation is, on the contrary, very much heightened by the compression, friction, and motion of the substance to be tasted between the tongue and palate. The cause of this may be either that the impression is rendered more intense when combined with a mechanical impetus, as is the case in the perception of odours; or that the excitability of the sentient points of the tongue's surface soon becomes exhausted, so that motion is necessary to bring the foreign substance into relation with fresh parts of the nerve. The hypothesis recently proposed by Raspail that a reciprocal action is here excited between the two living surfaces brought into contact with each other is very improbable, since the friction of the substance to be tasted upon the tongue by any other means, without the contact of the tongue and palate, has the same effect.

Sensations of taste, independent of the application of sapid substances, have been hitherto little observed. We have instances of these sensations, however, in the nausea produced by mechanical irritation of the root of the tongue and soft palate; in the saline taste observed by Henle to be excited by the impression of a small current of air; and in the acid and alkaline tastes to which the application of galvanism by means of two plates of different metals to the tongue give rise. Reasons which render improbable the opinion that this last phenomenon is due to decomposition of the salts of the saliva are stated at page 623; [moreover, the same tastes can be excited by a mechanical stimulus.]

The re-action of the sense of taste seems capable of being excited also

through the medium of the blood, in the same way that the sense of vision is affected so as to produce flickering before the eyes, &c. by the presence of narcotic substance in the circulation. M. Magendie has observed that dogs, into whose veins milk has been injected, lick their lips with their tongue as if they tasted. It is probable that the sense of taste is sometimes modified, and peculiar sensations of taste excited, by internal changes in the condition of the nerves; but it is difficult to distinguish such phenomena from the effects of external causes, such as changes in the nature of the secretions of the mouth.

SECTION V.

Of the sense of Touch.

THE sense of touch is not confined to particular parts of the body of small extent, like the other senses; on the contrary, all parts capable of perceiving the presence of a stimulus by a sensation of mere touch, or a modification of the sensations of pain or pleasurable feeling, or of heat or cold, are the seat of this sense. The external causes exciting these sensations are mechanical, chemical, or electrical influences, and changes of temperature. The sense of touch, or common sensibility, extends throughout the whole animal and organic system, though its acuteness varies exceedingly in different parts. Even the special organs of the other senses are endowed with common sensibility, and hence are supplied with other nerves besides that of the particular sense peculiar to them. The nerves of touch are the posterior ganglionic roots of the nerves of the vertebral or spinal system, which includes some of the cerebral, and all the spinal nerves. The sensitive fibres contained in these posterior ganglionic roots go, for the most part, to compose with other fibres the nerves of animal life; but a smaller part of them assist in forming the nerves of organic life, endowing the latter nerves with their obtuse sensibility, the former with their vivid sense of touch. The so-named common feeling (*cœnæsthesis*) is not a peculiar sense, but merely the common sensibility of the internal parts of the body, which is capable of endless modifications, from the feeling of fatigue to that of pain in disease, and from the feeling of ease to that of pleasurable sensations and tickling in the state of health.

Parts endowed with the sense of touch and common sensibility. Organs of touch.—Touch, in its more limited sense, does not differ essentially from the sensibility more generally enjoyed by the textures of the body: its peculiarity depends solely on the relation of the sensitive organ to the external world. Every part of the surface endowed with sensibility has the sense of touch, inasmuch as it is capable of perceiving the contact of external bodies. It becomes especially an organ of touch, when its sensibility is very delicate and it is endowed with motion. The organs of

touch are therefore the whole extent of the skin, but more especially the hands, the tongue, the lips, (particularly in feline animals, and seals and walruses, where they are provided with vibrissæ, the pulps of which are very sensitive, and plentifully supplied with nerves,) the proboscis and mouth of some animals, the tentacles of the mollusca, the antennæ and palpi of insects, and the finger-like processes of the pectoral fins of the Triglæ, the nerves of which arise from a series of special lobes or enlargements of the spinal cord. The part developed for the purpose of touch in the skin is the corpus papillare, consisting of small elevations of the surface of the cutis, visible by the aid of a lens, which are invested by a sheath of the rete Malpighii, and contain the terminations of the nerves.*

The minute description of the organs of touch in different animals belongs to comparative anatomy.

The parts of the body in which the sense of touch or common sensibility has its special seat, are certain regions of the central organs of the nervous system, and the vertebral or spinal system of nerves; and by these it is imparted to most organs of the body.

There are parts of the nervous centres which appear to be perfectly insensible; for example, the surface of the hemispheres, which, there have been frequent occasions to observe, both in man and animals, may be wounded without the production of any pain. In cases where, after injuries to the head, it has been necessary to remove partially destroyed and projecting portions of brain, while the patient was in a state of consciousness, the operation has never caused pain, or even been felt.

Other parts of the nervous centres, on the contrary, are very sensible; but the sensations of which they are susceptible are not uniformly the same. When the parts of the central organs connected with the sense of vision are irritated, appearances of light are perceived. It is an old observation, that pressure upon the brain in the human subject gives rise to the perception of luminous appearances and flashes like lightning. But there are other parts of the brain which are susceptible of the varieties of common sensation; for although pain in the head is in many instances seated merely in the nerves of the exterior investments of the brain, yet the possibility of such sensations, as of tension or pain, being seated in the brain itself, is shown by cases of chronic affections of that organ, where the patient has had a more or less distinct consciousness from his sensations of the seat of the disease.†

The spinal portion of the encephalon and the spinal cord are susceptible only of the modifications of common sensation, which are perceived both at the situation where they are excited, namely in the middle line of the back, and in the external parts to which the spinal nerves are distributed, having there the character either of pain or of the creeping of insects,

* See Breschet and Roussel de Vauzème, *Ann. d. Sc. Nat.* 1834. t. i. p. 167.

† See Nasse, *über Geschwülste im Gehirn*, p. 26; and Abercrombie, on *Diseases of the Brain*, translated into German by De Blois. Bonn, 1821.

“formicatio.” The local sensations in the back are sometimes unattended with those in the peripheral parts, and *vice versâ*. The cause of these remarkable differences is unknown.

The laws regulating the production of sensation in nerves by irritation applied to themselves, have been fully considered in the book on the physiology of the nerves. It only remains for us, therefore, here to speak of the sensations caused by stimuli applied to their peripheral extremities.

The horny tissue and teeth are perfectly destitute of sensibility, though their matrix or pulp is supplied with nerves as well as with vessels. The sensation in the teeth produced by the contact of acids must therefore be regarded as an affection of their pulp; and it is easy to conceive how the acid may be conducted to that part by the capillary dental tubes, whether we suppose it to act first on the ivory of the tooth where it is uncovered, or to reach the ivory through the clefts which are so frequent in the enamel.

Tendons, cartilages, and bones are in the healthy state void of sensibility, as Haller proved by numerous experiments. Haller’s experiments also seemed to show that the periosteum is insensible. The dura mater, however, appears to constitute an exception; it is at least certain that it is supplied with nerves. (See p. 776.) In the state of disease, however, the bones, like the viscera of the chylopoietic system supplied by the sympathetic, become the seat of severe pain.*

The sensibility of the muscles is much less than that of the skin, a fact which is evident in the operation of acupuncture. The skin itself varies very much in different parts in the degree of its sensibility, which is probably proportionate to the number of nervous fibres distributed in it. An account of Professor E. H. Weber’s observations relative to this subject has been given at page 700. At the same parts of the surface, where two small bodies applied at a very little distance from each other were recognised as separate bodies, the differences of temperature, and the weight of bodies applied, were also, according to Professor Weber’s observations, most accurately recognised. The weight of bodies produced a greater impression at these parts; a body placed upon the volar surface of a finger seemed heavier, its pressure was perceived with greater intensity, than when it was laid upon the skin of the forehead.

The sensibility of the mucous membranes is very great in the respiratory apparatus, in the organs of sense, and in the generative organs, where they are supplied by nerves of animal life; while in the intestinal canal the sensibility of the analogous membrane is very slight in the normal condition, though in disease it may be exaggerated to great intensity. The external and internal tegumentary system differ from each other, moreover, in the circumstance that the tingling sensation, or “formication,”

* For an account of the numerous experiments which have been instituted relative to this question, see Haller’s *Element. Physiol.* iv. p. 271—289.

which is frequently excited in the skin by internal causes, and particularly by affections of the spinal cord, appears to be never felt in the mucous membranes.

Various modifications of common sensation.—The sensations of the common sensitive nerves have as peculiar a character as those of any other organ of sense. The sense of touch renders us conscious of the presence of a stimulus, from the slightest to the most intense degree of its action, neither by sound, nor by light, nor by colour, but by that indescribable something which we call feeling, or common sensation, the modifications of which often depend on the extent of the parts affected. The sensation of pricking, for example, informs us that the sensitive particles are intensely affected in a small extent; the sensation of pressure indicates a slighter affection of the parts in a greater extent, and to a greater depth. It is by the depth to which the parts are affected, that the feeling of pressure is distinguished from that of mere contact.

The sensation of a blow or shock arises from a sudden change being produced in the state of the nerves by an external or internal influence,—namely, by the mechanical influence of a solid body, or by an electric discharge. A sudden discharge of nervous principle from the brain also, as at the moment of fright, is sometimes productive of the sensation of a shock or blow. The peculiarity of this sensation, therefore, depends in no way upon the mechanical action of the foreign body.

In some other senses, a rapid succession of impulses produces peculiar sensations, which vary in their quality according to the number of the impulses communicated to the nerve within a given time,—such, at least, is the case with the sense of hearing, and, perhaps, also with that of vision,—while on the senses of taste and smell this mode of excitement has no such effect. How is it with the sense of touch?

A rapid succession of equal impulses, such as produces the sensation of sound in the organ of hearing, is felt by the nerves of touch as a thrill or tremour. If the impression of the vibrations be more intense, and the part which is the seat of it very sensible,—such as the surface of the lips,—it may give rise to the sensation of tickling; this sensation is produced, for example, by bringing a vibrating tuning-fork very close to the lips; it is also very readily excited in the tongue. It might be imagined that the sensation of tickling when arising from other causes—such as the slight contact of another body, and the sensation of sensual pleasure so nearly allied to it, are both dependent on vibrations of the nervous principle itself with a determinate rapidity within the nerves. The sensation of tickling, or the allied pleasurable sensations, may be produced in all parts endowed with common sensibility; but they are experienced with greatest intensity in the generative organs; less strongly in the female breast, in the lips, in the skin generally, and in the muscles.

The sensation of pain seems to depend on the violence with which the nerves of touch are irritated.

The feelings of warmth and cold are most frequently caused by changes produced in the condition of the organized tissues by the imponderable physical agent, caloric ; but they are frequently present when no variation of temperature can be detected by the thermometer, being then produced by some internal change in the condition of the nerves. Moreover, the sudden sensation of very great cold, and that of burning heat, appear to be very similar.

In comparing the temperature of different media by means of the sense of feeling, the degree of capability of the media for conducting caloric must be taken into consideration. The same heat acts with much greater intensity upon our skin, and produces the sensation of much greater warmth, when the medium by which it is communicated to our sense is water, than when it is air. Cold water also feels much colder to us than air of the same temperature, because water conducts away the caloric of our body more rapidly.

Reciprocal influence of the mind and the sense of touch.—When the activity of the sensorium is directed to a sensation, it is perceived ; while, if the mind does not thus co-operate, the organic conditions for the sensation may be fulfilled, but it remains unperceived. The distinctness and intensity of a sensation in the nerves of touch, or common sensibility, depends on the mind's co-operating for its perception. A painful sensation becomes more intolerable the more the attention is directed to it. A sensation in itself inconsiderable, as an itching in a very small spot of the skin, is thus rendered very troublesome and enduring. When a person speaking to us spirts particles of saliva in our faces, the idea attached to the saliva causes the sensation it produces to be much increased in intensity and duration.

By the co-operation of the mind, and the application of experience previously gained, we attain the faculty of referring sensations at one time to our own body, and at another to external objects. Strictly speaking, we can feel only the present condition of our nerves, whether this condition be excited by internal or external causes. When we apply our hand to an external object, we do not feel the object itself, but only the hand which touches it ; the mind, however, having already a conception of the external body, refers the sensation to it, and we say that we feel it. We have explained, at page 1080, how the idea of external objects, as distinguished from our own body, is first obtained. The ideas which we obtain of different objects by the touch have their source in the knowledge of the natural relation of the different parts of our body which is implanted in our sensorium ; a faculty which is rendered more acute and accurate by the exercise of the sense of touch, and in the adult attains such a degree of developement, that, when our limbs are out of their natural position, if our attention is not directed to this circumstance, we deduce from sensations excited in them the same ideas that we should do had they their natural relation to each other. Hence, in the experiment, mentioned by Aristotle, of rolling a globular body between two fingers of one hand

which are crossed over each other, the sensation obtained is that of two convex surfaces opposed to each, and apparently belonging to two separate spheres.

A sensation in a part endowed with touch appears to the sensorium to be, *cæteris paribus*, more intense when it is excited in a large extent of surface than when it is confined to a small space. The temperature of water, into which he dipped his whole hand, appeared to Professor Weber to be warmer than water of really higher temperature, in which he had immersed only one finger of the other hand. Similar observations may be made by persons bathing in warm or cold water.

As every sensation is attended with an idea, and leaves behind it an idea in the mind which can be reproduced at will, we are enabled to compare the idea of a past sensation with another sensation really present. Thus we can compare the weight of one body with another which we have previously felt, of which the idea is retained in our mind. Professor E. H. Weber was, indeed, able to distinguish in this manner between temperatures experienced one after the other better than between temperatures to which the two hands were simultaneously subjected. This power of comparing present with past sensations diminishes, however, in proportion to the time which has elapsed between them.

Sensations connected with muscular motion.—The muscles are endowed with a certain degree of sensibility, and, in spasmodic affections of their nerves, become the seat of intense sensations. These sensations are not, however, always proportionate to the degree of the muscular contraction; which renders it probable that the motion and sensation of the muscles are not due to the same nervous fibres. Thus, for example, the sensation of cramp in the muscles of the calf may be very severe, though the extent of muscular motion attending it is very slight. The same circumstance is sometimes observed in cramp of the digastric muscle of the lower jaw, which, when there is a disposition to repeated yawning, occasionally follows a violent movement of that kind: the pain then felt in the anterior belly of the digastric muscle is often extremely severe, though the movement of yawning has ceased, and the spasmodic action of the muscles has much diminished.

The sensation which informs us of the contraction of muscles enables us to estimate the degree of force exerted in resisting pressure or in raising weights. The perception of weight is more accurate than that of mere pressure, according to Professor Weber, who states that a difference between two weights may be detected when one is only one-twentieth or one-fifteenth less than the other. It is not the absolute, but the relative amount of the difference of weight which we have thus the faculty of perceiving.

It is not, however, certain that our idea of the amount of muscular force used is derived solely from sensation in the muscles. We have the power of estimating very accurately beforehand, and of regulating, the amount of

nervous influence which it is necessary to emit from the brain for the production of a certain degree of movement. When we raise a vessel, with the contents of which we are not acquainted, the force we employ is determined by the idea we have conceived of its weight. If it should happen to contain some very heavy substance, as quicksilver, we shall probably let it fall; the amount of muscular action, or of nervous energy, which we had exerted, being insufficient. The same thing occurs sometimes to a person descending stairs in the dark; he makes the movement for the descent of a step which does not exist. It is possible that in the same way the idea of weight and pressure in raising bodies, or in resisting forces, may in part arise from a consciousness of the amount of nervous energy transmitted from the brain, rather than from a sensation in the muscles themselves. The mental conviction of the inability longer to support a weight must also be distinguished from the actual sensation of fatigue in the muscles.

So, with regard to the ideas derived from sensations of touch combined with movements, it is doubtful how far the consciousness of the extent of muscular movement is obtained from sensations in the muscles themselves. The sensation of movement attending the motions of the hand is very slight; and persons who do not know that the action of particular muscles is necessary for the production of given movements do not suspect that the movement of the fingers, for example, depends on an action in the forearm. The mind has, nevertheless, a very definite knowledge of the changes of position produced by movements; and it is on this that the ideas which it conceives of the extension and form of a body are in great measure founded. The sensorium may possibly derive this knowledge, independently of sensations in the muscles, from the consciousness of the groups of nervous fibres to which it directs the current of nervous energy. The accuracy with which the muscular movements are regulated and proportioned to their object, or the manifestation of the muscular sense, is most remarkable in all those movements by which the equilibrium of our own body, or of other bodies supported by us, when the base of support is small, is maintained; and also in the preservation of our balance during voluntary and involuntary movements of our whole body.

Touch, in its more limited sense, or the act of examining a body by the touch, consists merely in a voluntary employment of this sense combined with movement, and stands in the same relation to the sense of touch or common sensibility, generally, as the act of seeking, following, or examining odours does to the sense of smell. Every sensitive part of the body which can, by means of movement, be brought into different relations of contact with external bodies, is an organ of "touch." No one part, consequently, has exclusively this function. The hand certainly is best adapted for it by reason of its peculiarities of structure,—namely, its capability of pronation and supination, which enables it, by the movement of rotation, to examine the whole circumference of a body; the power of op-

posing the thumb to the rest of the hand, and the relative mobility of the fingers. Other conditions for the exercise of the sense of touch in great perfection are, great sensibility of the part, and a distinct perception of impressions on separate points of the sentient surface. The regular grooving of the skin of the palm, with the arrangement of the papillæ in regular series, must increase the delicacy of touch, inasmuch as the inequalities of the skin will more readily detect the inequalities of the bodies touched, and are better adapted for receiving distinct impressions from them.

In forming a conception of the figure and extent of a surface, the mind multiplies the size of the hand or fingers used in the inquiry by the number of times which it is contained in the surface traversed; and, by repeating this process with regard to the different dimensions of a solid body, acquires a notion of its cubical extent.

Sensations left after impressions;—modification of sensations by contrast.—The after-sensations left by impressions on nerves of common sensibility or touch are very vivid and durable. As long as the condition into which the stimulus has thrown the organ endures, the sensation also remains, though the exciting cause should have long ceased to act. Both painful and pleasurable sensations afford many examples of this fact.

The law of contrast, which we have shown to modify the sensations of vision, prevails here also. After the body has been exposed to a warm atmosphere, a degree of temperature very little lower, which would under other circumstances be warm, produces the sensation of cold; a sudden change to the extent of a few degrees from a warmer temperature, which has been of long duration, will produce the sensation of extreme cold. Hence the facility with which catarrhs are contracted even in the warmest climates. Heat and cold are relative terms. A particular state of the sentient organ causes what would otherwise be warmth to appear cold. A diminution in the intensity of a long-continued pain gives pleasure, even though the degree of pain that remains would in the healthy state have seemed intolerable.

Sensations dependent on internal causes are in no sense more frequent than in the sense of touch. All the sensations of pleasure and pain, of heat and cold, of lightness and weight, of fatigue, &c. may be produced by internal causes. Neuralgic pains, the sensation of rigor, formication, or the creeping of ants, and the states of the sexual organs occurring during sleep, afford striking examples of subjective sensations. The increased force of the current of blood synchronous with the heart's contraction excites sensations in almost all the organs of sense; in the retina the periodic appearance of a luminous spectrum, in the ear a periodic buzzing sound, in the nerves of touch a feeling of pulsation. There are mechanical causes for this sensation of pulsation, but it may be induced by a particular condition of the nerves; thus, it is often experienced in parts to which the blood is not sent with increased force.

The mind also has a remarkable power of exciting sensations in the nerves of common sensibility ; just as the thought of the nauseous excites sometimes the sensation of nausea, so the idea of pain gives rise to the actual sensation of pain in a part predisposed to it. The thought of anything horrid excites the sensation of shuddering ; the feelings of eager expectation, of pathetic emotion, of enthusiasm, excite in some persons a sensation of " concentration " at the top of the head, and of cold trickling through the body ; fright causes sensations to be felt in many parts of the body ; and even the thought of tickling excites that sensation in individuals very susceptible of it, when they are threatened with it by the movements of another person.

These sensations from internal causes are most frequent in persons of excitable nervous systems, such as the hypochondriacal and the hysterical, of whom it is usual to say that their pains are imaginary. If by this is meant that their pains exist in their imagination merely, it is certainly quite incorrect. Pain is never imaginary in this sense ; but is as truly pain when arising from internal as when from external causes ; the idea of pain only can be unattended with sensation, but of the mere idea no one will complain. Still, it is quite certain that the imagination can render pain that already exists more intense, and can excite it when there is a disposition to it.

The sympathies of the sense of touch with the other senses, and with muscular movements, are dependent on reflex nervous action ; they have been discussed in the Chapter on Nervous Reflexions in the Book on the Physiology of the Nerves, where the sympathy between the secretions and sensitive impressions has also been considered.

BOOK THE SIXTH.

Of the Mind.

SECTION I.

Of the nature of the mind generally considered.

CHAPTER I.

OF THE RELATION OF THE MIND TO ORGANISATION AND MATTER.

A. Results of observation and experiment.

IN the introductory portion of this work, which treated of general physiology, a comparison was drawn between an independent organised body or organism, and a piece of mechanism, the component parts of which are combined for the fulfilment of a determinate purpose, and depend for their individual action on the harmony of the whole. In this comparison we met with more points of dissimilarity than of resemblance. The organism and the piece of artificial mechanism resemble each other in the well-adapted combination of their several parts for the production of a general result; but the organic body is distinguished by the power of reproducing the mechanism of its own organs, in the form of the germ, and of thus propagating itself. Again, not merely does the action of organic bodies depend on the harmony of their component organs, but this harmony itself is an action of the organism; while the cause to which each part of the organised system owes its state and properties resides not in itself, but in the cause which produces and maintains the whole. A piece of mechanism is formed in accordance with an idea held in view by the artificer, this idea being the purpose for which it is intended. An "idea" also regulates the structure of every organism, and of each of its component organs. In the former case, however, the ruling idea exists external to the artificial mechanism, namely, in the mind of the artificer; while the idea, which is the cause of the harmony of organic bodies, acts in the organism itself, exerting in it a formative power, though without consciousness, and in obedience to determinate laws.

The cause which produces an organism being constrained to work out a predetermined plan, or pre-existent idea, necessarily maintains the form and endowments of one organism distinct from those of another, which is constructed according to a different idea. But, although

this is the case, yet the different organic forms are connected by a more general principle of construction, which arranges them in classes, orders, families, genera, and species. The genus exists only in the different species which are quite independent of each other, and not as a distinct organism producing these species. Everywhere in the animal, as well as in the vegetable kingdom, we see manifested a perfect unity in the general plan, together with all logical modifications in the realisation of it: yet each of the various species which constitute a genus, cannot depart from its own specific type of structure and mode of action; so that the species ceases to exist as soon as all living individuals belonging to it and their germs have perished. Except in this sense, the species is immortal; since the vital force or principle which creates and maintains its organisation is successively imparted by the perishing parent organisms, to the new beings which they produce.

The action of the vital principle which forms organic beings in conformity with determinate ideas, is known to us only by its effects *in* organic beings. If organic forms were produced spontaneously and independently of organisms already existing, we should have the phenomenon of a vital force operating in conformity with determinate ideas, elsewhere than in living organic beings. But the doctrine of the generatio *æquivoca* is constantly losing ground before the advances of strict investigation, and preserves merely the form of an hypothesis alike destitute of proof and incapable of demonstration.

It is in no way probable that the vital principle which produces the definite compound structure of an organism is itself a compound of distinct parts; and the same may be said of the sentient mental principle of animals. That which owes its integrity to its compound structure, must be rendered imperfect by division; but the organising principle of a plant or animal may be divided at the same time with the plant or animal in which it resides, and yet retain all its organising power. Thus the parts of a divided polype or planaria become, or are, from the moment of their division, independent organic beings endowed with the power of producing the proper organisation of their species. So it is likewise with the sentient and thinking principle of animals; if indeed that principle is distinct from the vital principle. It cannot be a compound of different parts; for if it were, the division of an animal would necessarily destroy its integrity; and we know that an animal may be divided, and yet the mental principle in each portion remain perfect, manifesting sensation, volition, and desires. Whatever is true with regard to the mental principle of other animals, may be predicated of the mind of man; for everything which feels and moves voluntarily in accordance with its desires, is endowed with a mind. Such, indeed, was the remark of Aristotle, who, in his *Essay on the Mind*, says: "As soon as

they feel, they must have thoughts and desires; for where there is sensation, there must be pain and pleasure; and where these exist, desires must exist likewise."

The vital principle and the mind or mental principle of animals resemble each other, therefore, in this respect: they exist throughout the mass of the organism which they animate; but, unlike it, are not composed of separate parts, and, when divided together with the organism, do not suffer any diminution or change of their powers.

In a former part of this work it has been proved that the vital principle has not its special seat in any one organ. The facts adduced in support of this position were the following:—First, the presence and activity of the vital principle in the germ before any organs are developed, and in anencephalous and acephalous monsters; secondly, the persistence of life in separated fragments of animals and plants, and the development of these fragments into perfect organisms; and, lastly, the phenomenon of the spontaneous organisation of the germ of the higher animals and man after its separation from the parent system. The separation of the germ from the parent is an instance of true division of an organism; the part separated in this case merely differing from the sprout cut from a plant, or the fragment of a divided animal in its possessing only the organising power, but not the already organised structure. The same force is in action in both cases. The circumstance of the stimulus to organisation being afforded to the germ by fructification, and the existence of distinct male and female sexes, are not valid objections to this proposition; since the influence of a fructifying matter is not necessary for the preservation of life in parts already organised, when they are separated from the parent system; and even the dualism of the sexes may be reduced to a mere dualism of the sexual organs in one individual, as we see exemplified in plants and hermaphrodite animals, some of which latter are capable of self-impregnation.

It was also shown at the same time that the mental principle, or cause of the mental phenomena, viz. the conception of ideas, thought, &c. cannot be confined to the brain; but that it exists, though in a latent state, in every part of the organism. In proof of this the fact was adduced, that new animals, developed from the germ and semen, from the buds of animals propagating by gemmation, or from the separated portions of those which divide spontaneously, manifest sensations, volition, and desires, as soon as the organs necessary for mental action are formed.

At the same time, however, a difference between the vital and the mental principle was pointed out in the dependence of the latter for its manifestation, as a conscious mind, on one organ—the brain. The mental principle exists only in a *potential* state in the germ, and is

totally unable to manifest itself by perception, will, ideas, or thought, until the whole organisation of the brain is perfected by the plastic vital force.

The development of the germ is dependent on certain external conditions. The vital principle resident in it is unable to effect the organisation of its component matter until this matter is exposed to certain external influences, such as warmth and air. Without these aids the germ cannot assimilate the surrounding nutriment, owing to the unfitness of the latter to combine with the substance of the germ, so as to preserve its necessary chemical properties and composition. The vital principle, therefore, may itself exist in a latent or merely potential state in the germ, just as the mental principle has that condition in all parts of the fully developed organism except the brain. From these latter remarks, we may clearly infer the points of dissimilarity, as well as those of agreement, between the vital principle and the sentient mental principle. Both are simple, not composed of dissimilar parts, and therefore are divisible, together with the organic substance which they animate; and both are capable of existing in a latent state. But the vital principle requires for the manifestation of its organising powers only the chemical co-operation of certain external influences; while for the action of the conscious mind the presence of matter already organised with the structure of the brain is essential.

The germ and young animal are not distinguished from the fully developed organism merely by the imperfection of their organisation, and by the smaller size of those organs which are developed in the young animal. A more essential difference between the germ and the organism in which the whole structure is perfected, and which is capable of generation and of producing offspring, consists in the latter being a multiple of the germ. Hence only can we explain the fact that a part of the fully organised or "multiple" animal may separate itself and become a new animal, while the rest of the parent organism loses nothing of its power of further organisation.

The development of the multiples of the germ by the process of growth will, in the Section on Generation, be demonstrated to take place both in plants and in the Coralline Polypifera, Naides, Vorticellinæ, Polygastrica, Planariæ, and Hydræ. Here we shall see the multiplication of the original organism manifested by the formation of buds, and by spontaneous division, and in some instances the multiple character will be rendered evident by the persistence of life in portions separated by artificial division.

The portions of a divided Hydra have not at first the whole structure of the perfect animal, but they soon develop that structure within themselves. This fact shows us that the multiplication of an individual does not necessarily consist in the increase of analogous forms with analogous

endowments, but may take place only virtually, in such a way that the forms produced are unlike the original, though their virtual endowments are the same. And thus we are led to understand the process subsisting in the higher animals, which, though capable neither of propagation by spontaneous division, nor of living after artificial division, yet are virtually a multiple of the germ from which they were developed. Here a part of the multiple animal cannot separate from the rest in a state capable of continued life and development except when it has become isolated in the form of an undeveloped germ. Now, in all the modes of propagation to which we have alluded, those of spontaneous or artificial division, germination, and sexual generation, both the vital principle and the mental principle, as we have before shown, undergo division.

The questions next present themselves, how is it possible for the growth of an organic being to cause a multiplication of its organising force? and how is the divisibility of the mental principle, acquired at the same time, to be explained or understood? Is it a peculiarity belonging to the nature of the vital principle, and also of the mental principle, as a potential essence, that their extension through a large mass of matter, and their subdivision, is incapable of diminishing their intensity? or does the mere assimilation of new matter by a growing organism give rise to an increase of those principles, in consequence of their being contained in the nutritive matter itself in a latent state, though they are incapable of manifesting themselves until the matter is assimilated by an organic body?

The supposition last proposed necessarily involves a second, namely, that the principles of life and mind exist in a latent state in all matter; for although animals are capable of assimilating merely vegetable matters, plants, on the other hand, increase their substance from inorganic materials: indeed, unless there were such a new formation of organic matter from the inorganic elements, organic beings must at length perish, owing to the great destruction of organic substances which takes place by putrefaction and combustion.

The alternative contained in the two questions proposed above, is the farthest limit which our actual knowledge enables us to reach in the investigation of the relation subsisting between the vital and mental principles on the one hand, and organisation and matter on the other. At this point the inquirer is constrained to leave the field of empirical physiology, and to enter that of hypothetical speculation and philosophy. In the remarks which I have made in the foregoing pages, I have carefully avoided all considerations of the latter kind, my object having been, by a careful induction from facts, to develop those views which have the greatest semblance of truth in their favour. Moreover, as it appears to me very inadvisable to adopt any other mode of inquiry in our science, or arbitrarily to exchange the strictly inductive method for

that of mere speculation, I shall, in the following pages confine myself to a simple exposition of the theories contained in the two questions already alluded to, without supporting either the one or the other. I shall not follow exclusively any special form of philosophy, but shall explain both systems without mixing up with them the consideration of physiological facts, though at the same time I shall endeavour to make their bearing on those facts as evident as possible.

B. *Cosmological Systems.*

I. *Hypothesis of the dependence of organisation and the mental phenomena on active innate "ideas" or spiritual essences implanted in organic bodies.*

This hypothesis admits that in every part of the universe ideas of the Divine Spirit are being carried into operation; but supposes that in organic beings alone are implanted such ideas as are capable of constantly reproducing their kind, and of developing in matter the mechanism proper for the actions of organic bodies. The active "idea" of an organic body is, therefore, an emanation of divinity, living in that body and its products from the period of creation downwards. This "idea" is the only part of the organic body which is permanent, for the matter of the body is constantly leaving it, while new matter is as constantly being subjected to the influence of the innate spirit. In matter itself there is neither soul nor life, even in a latent or potential state. All the vital and mental phenomena presented by matter after its assimilation by an organic body, are due to the idea which exists in and rules the organism. This is the doctrine taught in a mythical manner in the *Timæus* of Plato,* and is indeed the view most generally adopted respecting the relation in which the vital and mental principles stand to the body. According to this theory, the vital idea, or spirit, may after death dissolve its connection with the body, and may return to the divine source whence, at the creation of animated beings, it had emanated. The soul, therefore, is essentially independent of matter, and is connected with it only by a bond capable of solution. The proper endowments of matter are wholly of a physical nature. The various fables respecting the condition of the soul after death, the doctrines of the Pythagoreans and Plato, concerning the fate of spirits after death, and the notions of the New Platonists and Mystics, with respect to the soul freeing itself from the bonds of matter even in this life, as well as the practical application made of these views, are all modifications of the same fundamental cosmological theory, the main propositions of which we have just stated,—to wit, that the soul is independent of the body; is not a property of it or of matter in any form; and is only united with

* [The article on Plato's writings and philosophy in the *Encyclopædia Britannica*, contains a full exposition of the theory of "innate ideas."]

matter in living organic bodies. The belief in this doctrine is strengthened and confirmed by the interest which the "self" of each individual feels in his continued personal existence; and by the hope in the duration of this existence even beyond the grave. For few are they who are content to merge their personal being in that of the universal spirit, and, with Fichte, to regard the mental existence, even in this world, as the mere striving after infinity and eternity.

Now life and mind, or the animating "idea," not being latent properties of all matter, the increase and division of animated organic beings, and the simultaneous division of the vital and mental principles cannot, according to this view, be ascribed to the assimilation of new matter in the process of nutrition, but must be regarded as due to a property of the vital and mental principles themselves, which, contrary to every attribute of matter, renders them capable of division, *ad infinitum*, without any diminution of their power or intensity. Such a property it is certainly difficult for the mind to conceive. But this fundamental hypothesis of the animating ideas of organic bodies being independent of their material substance, and emanations from the Divine Spirit, renders it more easy to understand how the different individual organisms, and their classes, orders, families, genera, and species can have a distinct and independent existence; while they, at the same time, manifest such distinct signs of the original influence of one ruling idea. This general idea is so logically followed out in all the modifications presented by the genera of one family, that zoologists, from the knowledge of the characters of a family, and of some of the genera belonging to it, can frequently predetermine the existence of the other genera and their peculiarities. The hypothesis of original innate spirits or ideas agrees also with the known law of creation,—that if in either of the organic kingdoms all the individuals of a species perish, the form is not restored by any general life of nature; and the original identity of structure of the germ of the most various organic beings, constituted, as it always is, of a cell with a nucleus, seems to prove that the cause of the variety of classes, families, genera, and species of animals and plants developed from the germ resides not in the structure or chemical property of the germ, but in the idea or spirit implanted in it at its creation.

II. *Pantheistic view of a universal spirit, and its relation to matter.*

Directly opposed to the foregoing theory is the doctrine that the principle of life is inherent in all matter; that so far from being something superadded, it is in fact a property of matter itself, although it manifests itself in the various forms of organic nature, only under certain conditions, and when the matter has a determinate composition

and structure. As soon as matter is assimilated by an organic being, it falls under the influence of conditions which compel the vital principle latent in it to manifest itself in the definite form of the organic body. According to this view, the multiplication of the organic force during the growth of a living being, and the capability of division which organisms possess, are intelligible. When organic beings die, moreover, merely the conditions necessary for the manifestation of life in their definite forms are lost; the matter returns to the general lap of Nature, still endowed with the vital principle, and still capable of manifesting life.

The doctrine of pantheism, and at the same time of materialism, is here expressed in general terms, without reference to historical peculiarities, and in the form best adapted for illustrating the problems alluded to in the preceding inquiry. Cosmological theories of this kind are contained in a more or less varied form in the writings of the philosophers of ancient Greece, Heraclitus, Anaxagoras, &c. Anaxagoras taught that all might originate in all; and that "the spirit" was the soul of all things, and the universal form of all things. According to Heraclitus, animated beings receive the spiritual principle of the universe through the medium of their respiration and their senses. But by no philosopher has this theory of the world been more clearly laid down than by Giordano Bruno in his "*Dialoghi de la Causa, principio et uno.*" *

The following passages from the speculative treatise of Bruno, will afford the reader some insight into the nature of this system of cosmology, which has been reproduced, and more fully developed in the writings of modern philosophers.

"The soul of the universe fills and illumines the whole world, and instructs Nature in the production of the genera and species of things in their proper form. This creative universal intellect stands in the same relation to the production of all the objects of Nature as our intellect does to our conceptions of genera and species."—*Loc. cit.* p. 4.

"The final cause which the great first cause, the creative soul of the universe, has in view, is universal perfection; and this consists in the development of all possible forms in the different parts and masses of matter,—an object in which the universal intellect takes such delight that it never rests from evoking all varieties of forms from the womb of matter."—P. 45.

* See the translation of this work in Rixner and Siber's "*Leben und Lehrmeinungen berühmter Physiker am Ende des 16. und Anfang des 17. Jahrhunderts, als Beiträge zur Geschichte der Physiologie.*"—v. Heft. Jordanus Brunus, Salzbach, 1824. [An account of the writings and speculative doctrines of Giordano Bruno, with some extracts from his works, will be found in Mr. Hallam's "*Literature of Europe during the Fifteenth, Sixteenth, and Seventeenth Centuries,*" vol. ii. p. 146.]

“ The universal cause of all things must be one soul, that soul, namely, which presides over all matter throughout the universe, and which being unity in itself, produces from matter, according to its faculty of receiving various forms, and according to its different active properties, the different objects of Nature with their different qualities. Thus some of these created things live devoid of sensibility, on account of their spiritual endowments, being either through their own feebleness (?) or other causes, oppressed by the preponderating matter.”—P. 56.

“ Although the heavenly bodies and nature generally do not possess the human faculty of thought or memory, it can by no means be inferred that they form their products without any intelligence or design; for even perfectly educated musicians and penmen, though they are little or not at all observant of that which they execute, do it with perfect regularity.”—P. 48.

“ I say, therefore, that a table as a table, a coat as a coat, leather as leather, and glass as glass, are not animated; but, as products of Nature and compound things, they have matter and form. How small and inconsiderable soever a thing is, it has always a part of the spiritual substance within it, which, if it finds a fit subject or basis, is ready to become a plant, or an animal.* In short, there is one spirit in all things, and no body is so small that it does not contain a portion of the Divine essence by which it is animated.”—P. 53.

According to this theory, then, organisms are products of the first of all causes,—bodies endowed with life, in which the vital and spiritual phenomena are manifested in a determinate form through the medium of a definite structure and chemical composition. This structure also has not arisen accidentally; for it has emanated from the creative spirit of God: and the ideal connection of all organic beings in their relation of classes, families, genera, and species, precludes the notion of their being the result of accident. As soon, however, as the so-called dead matter is brought within the sphere of action of the already existing organism, receives from it the same structure, and becomes subject to its vital principle, the capability of life, as yet latent in this matter, begins to manifest itself in a determinate form, which is included in that of the existing organised system. In this way the assimilation of new matter by an organic being gives rise to an increase of its organic force; and with this is combined the capability of multiplication by division. Phenomena, analogous to such a conditional mani-

* [In the German version, this sentence stands thus: — “ Be a thing ever so small and insignificant, it always possesses a part of the spiritual and animating substance, *which is always a fit basis, from which anything may be formed, as a plant or an animal.*” This appears to be an incorrect version, which mars the sense of the passage. The translator has therefore followed the Italian words, and the translation given by Mr. Hallam, *op. cit.* p. 149.]

festation of a principle of vitality latent in all matter, are known in physical science. Forces, or principles, such as electricity and light, for example, which are present in a latent state in bodies, are manifested when these bodies are subjected to certain conditions.

The doctrines of pantheistic cosmology are here merely sketched in a general manner. The elucidation of the different forms in which the philosophical systems of this school have been presented, is foreign to the design of this work. The only object held in view has been to offer for consideration the two principal hypotheses which take up the inquiry into the connection of life and mind with matter at the point where it passes beyond the domain of empirical physiology.

CHAPTER II.

OF THE MIND CONSIDERED IN A MORE LIMITED SENSE.

Distinction between the Mind and Life.

THE most general operations of life in organic beings are beyond the sphere of consciousness, and consist in the development and maintenance of the well-contrived organisation of those beings, and the reproduction of similar organisms. These operations of life are the same in plants and animals. In both kingdoms of organic nature the germ receives from the parent organism, as the foundation-stone of its structure, a cell with the nucleus attached to its wall; this is, in animals, the germinal vesicle with the germinal spot. The first steps in the process of organisation consist in the development of new cells of the same kind from similar nuclei. The germinal membrane of the animal ovum, according to Schwann's observations,* is constituted of an aggregation of cells, and the tissues of the fœtus are at first, according to the same observer, formed of cells, similar both in form and mode of origin to those of vegetable cellular tissue, having generally, attached to their walls, a nucleus around which they are developed. It is only when these cells become transformed into the permanent tissues that animal and vegetable structures assume their distinctive characters.

If we compare the mental phenomena, which animals and the human species alone present, with the operations of organisation common to them and plants, we find points both of resemblance and of difference. In both we see an accordance with design and with the demands of reason; but in the operations of the organising power this is effected

* Froriep's Notiz. 1838. N. S. No. 3. [See also Schwann's *Mikroskopische Untersuchungen über die Uebereinstimmung in der Struktur und dem Wachsthum der Thiere und Pflanzen*. Berlin, 1839. p. 63, and the analysis of this work in No. 18 of the *British and Foreign Medical Review*.]

without consciousness, while in the mental actions it is attended with consciousness and perception. Hence, in the vegetative operations of vitality, the manifestation of design is the result of necessity, not of choice; one fixed end only can be attained, and that is, the production of the special form and properties of the particular plant or animal. Everything which does not contribute to this end is disregarded, while all that is calculated to aid in its accomplishment is appropriated to that use. The "idea" of the particular species of plant is the sole theme which is again and again worked out. Just as in the formation of a piece of art by a well-practised artificer the rules for its construction are never deviated from, so it is in the organisation of a plant in accordance with the fundamental "idea" of the species.

In the mental phenomena, on the contrary, a much greater scope for arbitrary variety in action is allowed.

The various objects of the external world give rise to the perception of images which are reproduced and combined. The general quality of many objects being conceived by the mind, an image of this general quality is retained, and is called a general idea: these ideas, also, are combined with one another, and with other images; the act of doing which is thought. Here the creative action follows no model, but obeys merely the necessity of combining the different images, and of forming from them general or abstract ideas. The materials for these images may be supplied by the whole of nature, as far as it is cognisable by our senses. The mind may therefore be likened to an instrument which effects a most manifold reflection of the numerous things external to the organism, and within it, but yet in accordance with a simple law of combination. In organisation and life, on the other hand, like always reproduces like; the vital force creating the definite form of the species, with its peculiar properties, from the matter subjected to its action, while it takes no cognizance of external objects. If there is any similarity between the two processes, it lies merely in the images which form the material of mental action being disposed of according to an innate law of combination, just as matter and its principal properties are applied by the vital force, in obedience to the innate law of organisation.

The products, also, of mental action and of vitality are different: for, although it is possible for the mind to reproduce the objects of nature in the form of mental images, which are, as it were, signs of the things themselves, yet the whole process is one of mere consciousness;—from a mental image merely a mental image is produced;—from a sign, merely a sign. The organising force, or vital principle, on the contrary, realises the type of its operations in a material form. Again, amidst the general ideas conceived in the mind, the particular images or details can be separately produced; just as from the germinal membrane, which includes the general vitality of the animal, there are generated the

specialities of structure which are essential to the developed organism; but in the former case the products exist only in the consciousness of the individual, while in the latter instance a material tissue or organ is created. While, however, there are these differences between the processes of mental action and that of organization, both the mental and vital principles, in their relation to matter, present, as we have before seen, in most points the same properties (page 1335).

There is one class of phenomena in which the creative vital power of the animal organism takes a part in the operations of the mind, directing them, producing series of thoughts, like dreams, and determining the animal to certain acts which are called "instinctive." The bee is obliged to realise the cells of wax according to the type presented as a dream to its sensorium; each animal of a species must construct its habitation or its web on the same plan as those which have preceded it, or must sing as they have done, perform the same migrations, and protect its offspring while under the rule of passions which take their rise in the business of generation. The originator of all these ideas, which though obeyed and worked out by the mind of the animal, are not conceived by it, is the organising force, — the first cause of the organism, which reproduces like from like, and forms all the organs of the animal body in accordance with design. It is this power which determines animals to the act of sexual union, which enables the young to maintain their equilibrium without previous education, and leads the ducklings to seek the water, the mole to burrow, and the sloth to climb, in accordance with the structure of its limbs, which are adapted for that movement, and not for leaping. In these phenomena we see a power at work which has the attributes of the unconscious vital principle, and not those of the mind: but this power merely gives the theme of the instincts; their realisation is effected by an act of the mind itself. The cells of the bee, and the electric organs of the electric rays, therefore, owe their origin primarily to the same cause, but the immediate agents engaged in their construction are different, — the mind coming into play in the case of the bee's cells, and acting as the mediate agent in the realisation of that structure out of the body of the animal, which the vital force within it has determined.*

It is evident, therefore, that the vital force or principle may exert a direct influence on the formation of internal mental perceptions, and on the action of the mind; but it is, nevertheless, capable neither of proof nor of refutation that the primary cause of organisation and that of the mental phenomena are the same. It must consequently remain a

* The description of the instinctive acts of animals does not come within the plan and purpose of this work, but belongs to natural history. For information on the subject I refer the reader to Kirby and Spence's *Entomology*, and to Darwin's *Zoonomia*. The nature of the instinctive movements has already been discussed. See page 946.

matter of doubt whether the presence of the organising action alone in plants is owing merely to the want in them of the structure necessary for the manifestation of the mind, or whether it is the result of an original difference in the innate "ideas" implanted in them, as organic beings.

Action of the brain in the production of mental phenomena.—The peculiar quality of the mind is "consciousness,"—a something of which no further definition can be given, and which admits of description as little as the states or properties called sound, blue, red, and bitter. Just as it is the property of a specific nerve connected with the sensorium to have sensibility, so it is the property of the brain to have consciousness. The conception of ideas, thought, and emotion, or the affections, are modes of consciousness. There is no sufficient reason for admitting the existence of special organs or regions set apart in the brain for the different acts of the mind, or for regarding these as distinct powers or functions.* They are, in fact, as we shall presently show, merely different modes of action of the same power. Moreover, although the clearness of the ideas conceived, and of the thoughts, and the intensity of the emotions are affected by structural changes of the brain; and although the integrity of that organ is quite essential to consciousness; yet the action of the mind cannot be explained as the result of material processes, but must rather be regarded as in its essence independent of all material relations, though influenced in its clearness and intensity by the condition of the organ which is its seat. It is true that the mind is rendered conscious of external impressions only through the medium of the nerves of sense, and their action on the brain; but the retention and reproduction of the mental images of external objects of sense, are altogether incompatible with the notion of particular orders of ideas being fixed in particular parts of the brain; for example, in the ganglionic corpuscles of the grey substance. For the thoughts accumulated in the mind become associated in the most various manners,—in a chronological succession according to the relation of simultaneous occurrence, or according to their similarity or contrariety; and these relations of the ideas or thoughts to each other change every moment. It is certainly correct that structural changes of the brain are sometimes followed by partial loss of memory; facts relating to certain periods of time, or certain kinds of names, substantives, or adjectives being forgotten. But the occurrence of partial loss of memory of the first kind could only be used as an argument for impressions being successively fixed in the order of time in stratified parts of the brain,—a supposition which cannot be for a moment entertained. And if the perception of mental impressions and thought were ascribed in a general way to the ganglionic corpuscles; if the direction of the mind from individualities to general ideas, or from general ideas to individual-

* See p. 835* of the second edition of the first volume of this work, or p. 837 of the first edition.

ities, were supposed to depend on the relative exaltation of action of the peripheral part of a ganglionic corpuscle above its nucleus, or of the nucleus above the peripheral part; if the combination of ideas in an act of thought, or a proposition, for which the conception of object, predicate and copula, at the same time, is necessary, were explained by a reciprocal reaction of ganglionic corpuscles through the medium of intermediate processes acting as copulæ; or, lastly, if the association of ideas successively in the order of their first conception, or simultaneously according to their previous existence, were admitted to be attended with a successive action of certain united corpuscles, or a simultaneous action of several corpuscles,—if all these suppositions were adopted, we should be merely indulging in vague and groundless hypotheses.

It is best, therefore, to limit ourselves to the supposition that the clearness and distinctness of our ideas depend on the intensity of the organic actions of the grey globules or nucleated corpuscles of the brain.

Primitive ideas and abstract notions.—Philosophers of all ages have been led to inquire whether the correspondence observed to subsist between our thoughts and the relations of external objects, has its origin entirely in the evidence of our senses and the experience obtained through them, or whether it is also in part due to a pre-established harmony between the world of phenomena, the macrocosm, and the mind, the thinking microcosm; being, in the latter case, the result of laws necessary alike to the connection of the phenomena of nature and to the connection of the thoughts of the mind. According to those who adopt the former view, *nihil est in intellectu, quod non erat in sensu*. Those, on the contrary, who prefer the latter opinion, admit the existence of *à priori*, abstract notions innate in the mind, the categories of Aristotle, such as the notions of quality, quantity, relation and modality. These abstract notions are supposed to constitute the whole material of *à priori* thought, which, though excited by the experience of the senses, yet exerts a ruling influence over the impressions thus received. These notions, therefore, are not deduced from experience or observation, but are illustrated by it. Locke, in his analysis of the human understanding, arrived at the conclusion that the mind has no such original notions or ideas implanted in it, but derives all its purely abstract notions from experience, being unable either to create or to change them. But since the impressions on the senses are not themselves abstract ideas, the latter expressing rather the relation of the sensations, it becomes again a question how far the understanding can conceive anything, which, even if present, yet does not act on the senses; and whether the combination of sensations into a general idea is dependent on the existence of original ideas, or abstract notions of the mind, or on an impulse arising merely out of habit. The latter explanation was maintained by David Hume. According to his view,

the combination of ideas is owing to the frequency of their association, in consequence of which this association becomes a matter of subjective necessity; the association of cause and effect, for example, resulting from our being accustomed to see them succeed each other. Now, since we are entirely dependent on this habituated combination of our ideas, we can, according to Hume, have no "objective" knowledge.

Kant denied the truth of this doctrine, on the ground that the reality of *à priori* science, such as the pure mathematics, proves the existence of *à priori* ideas. Kant's pure ideas of the understanding are, 1. The category of quantity (comprehending unity, plurality, and totality). 2. That of quality (including reality, negation, and limitation). 3. That of relation (essence and accident, causality and reciprocation). 4. Modality (possibility, existence, necessity). These constitute the material of abstract thought, while, according to Kant, the ideas of space and time are the primitive forms of conception for the impressions of the senses,—the forms of all phenomena. We have, however, according to this philosopher, no knowledge of external things except that which we gain by the application of these principles to the results of experience, and to the recognition of what corresponds with the above categories.

That innate ideas may exist, cannot in the slightest degree be denied: it is, indeed, a fact. All the ideas of animals, which are induced by instinct, are innate and immediate; something presented to the mind, a desire to attain which is at the same time given. The new-born lamb and foal have such innate ideas, which lead them to follow their mother and suck the teats. Is it not in some measure the same with the intellectual ideas of man?

I believe that this question respecting the operation of the human mind can be answered in a way favourable neither to the hypothesis of Hume nor to that of Kant. From the frequent combination of two things in the mind, no other result can necessarily follow than that when the one is conceived, the other must also be associated with it; or that when an idea returns which had previously produced a pleasant or an unpleasant impression, this same impression may again be expected with certainty. In this way the dog connects the idea of blows with the perception of the stick, the association of the stick and blows having become through habit a thing of necessary occurrence. But to form an abstract conception of this association as of something common to many other combinations of ideas, under the notion of cause and effect, is a perfect impossibility, both to the dog and to every other brute animal. Brutes form no general notions. The cause of this difference between man and beasts does not lie in the comparative lucidity or obscurity of the impressions made on their minds respectively; for in this respect there is assuredly no superiority in the human mind. I am therefore

of opinion that the human mind also would never derive from the mere experience afforded by the senses, and from habit, the general abstract idea of causality, unless it had a certain power of abstraction,—a power, namely, of forming a mental something out of the returning combinations of two things, one of which requires the succession of the other.

On the other hand, I do not adopt the opinion that the mind is originally occupied by the primitive ideas of Kant, or the categories of Aristotle; these appear to be the fruit of experience and of the power of abstraction. But the original power by which the different categories are first acquired, from the observation of external nature, is the faculty of extracting the general property from many specialities or separate perceptions, in other words the power of forming an abstract notion, *λόγος*. When this faculty is present, the frequent experience that a particular external influence is necessarily followed by a change in one's-self, becomes connected with the observation of a similar relation between other facts, and produces in the mind the idea of "causality," or of the necessity of the change of one object by another; and in the same way all the general abstract ideas are produced by the mind rising from mere simple facts, communicated directly by the senses, to their general quality.

When an object perceived through the medium of vision no longer presents the same appearance as before, and the same fact is perceived with regard to numerous other objects, the distinct individual perceptions remain uncombined in the mind of an animal; but in the human mind the notion of "change" arises. This abstract notion includes merely that in which all the changing phenomena agree, but takes no cognizance of what is peculiar to the different phenomena. If the change is attended with an alteration of locality, the notion of "motion" is obtained. In phenomena which undergo changes, the different acts of the change agree only in the circumstance of their succeeding each other. This being conceived of many different phenomena gives origin to the notion of "succession."

The faculty of forming a general idea or notion is not, however, a distinct power of the mind acting on the simple perceptions; but it consists in the mutual reaction of allied perceptions amongst themselves. The human intellect has such a degree of development that many distinct perceptions or simple ideas may exist in it simultaneously, and react on each other. If many allied perceptions are present, which in one respect differ, while in another they agree, the points of difference amongst the mass of ideas become obscured, while only that which the different ideas have in common remains distinct. General ideas, or abstract notions thus obtained, are the more stringent in proportion as the application of which they are capable is more general.* The abstract notion of "causality" is more stringent than

* Herbart, *Lehrbuch der Psychologie*, p. 143.

that of "weight," because it finds its application in the relations both of mental and physical facts. If the notion of weight acquired by experience were capable of as extended application as that of causality, it would seem equally binding as the so-named primitive ideas.

The most general abstract notions formed in the manner above described are those of change, essence, infinity, finiteness, form, size, quality, space, time, motion, power, matter, object, subject, self, causality, existence, nonentity. Some of these may be conceived of all things material as well as immaterial. Such are the principal abstract notions which are called categories. Other general notions have been deduced solely from the perceptions of physical objects — "*phenomena*;" or solely from conceptions of the intellectual world — "*noumena*." Such are the notions of "matter," "force," "motion," "object," "subject," "self," &c.

The next question which presents itself for solution, respects the degree in which the conceptions of the mind correspond to their objects, and the possibility of their amounting to an absolute or complete knowledge of things. The great development and extension given to mental philosophy by some speculative writers, — as Bruno, Spinoza, Schelling, and Hegel, — led to the doctrine that this absolute knowledge of things was possible, and that the purely mental thought by the analysis of itself could produce thoughts entirely according with natural objects. The origin of this axiom is to be found in a passage from Bruno's writings, which we have already cited, where he says, — "This creative universal intellect stands in the same relation to the production of all the objects of Nature as our intellect does to our conceptions of genera and species." To a limited extent the power of reproducing in thoughts the properties of objects, is certainly possessed by the human mind; and that intellect which, by virtue of a talent for speculative inquiry, is capable of distinguishing and comprehending what is general and essential amidst the variable and accidental, or of discovering laws and general facts from which many phenomena may be deduced, has such a power in the greatest degree: but this can scarcely be called an absolute knowledge of things. Setting out with the notion of infinite existence, it has not yet been possible, even with the aid of what Hegel calls experiment, to give an absolute definition of light, of electricity, or of life; for this requires the previous knowledge of a different kind of absolute infinity from that on which philosophy is obliged to found her speculations. The analysis of a philosophical idea, even by the greatest philosopher, can, therefore, be merely a more or less successful exercise of the speculative talent according to a method which is not strictly conclusive.

When the properties of a thing have such a simple and necessary connection, that from its definition *all* its unknown properties may be

deduced, a complete knowledge of it is possible; as, for example, in the case of the simple relations of form and size. In the expressions of a triangle, circle, cone, &c. all their properties are given. Pure geometry, consequently, is an absolute science; but there are many other things in Nature of which it is impossible to give any such definition or notion as will involve the knowledge of all their properties. In these things, it is true, certain properties may be discovered which render it possible to deduce many other properties; but still, in natural objects, when the properties detected by the senses and those deduced by reason (*λόγος*) are known, the greatest part still remains undiscovered. Science does not here attain to the absolute discovery of the essence of things. It is only so far absolute as certain consequences follow with absolute necessity from a given axiom, (whether this be a thesis or a deduction from observation,) by which a certain series of phenomena or relations is explained. All sciences, when they have attained a certain degree of perfection, are susceptible of this mathematical mode of study. Speculative philosophy was treated in this manner by Spinoza. In the natural sciences, the object is to discover general facts from which, as from a fundamental principle, many others may be deduced. Those sciences, indeed, make the most rapid progress, which follow most closely the mathematical mode of investigation. The law of gravitation affords data for the deduction of the laws of motion of the planetary system; but the essence of gravitation remains a mystery. So, likewise, in electricity laws are known, from which the electro-magnetic phenomena may be deduced, as geometrical truths are deduced from their axioms; but we are still quite ignorant of the essential nature of electricity. The phenomena of the mind, also, may, like physical phenomena, be made the subject of observation. Psychology in all respects, indeed, resembles one of the physical sciences; the deduction of mental phenomena from known principles is quite possible; but we do not thereby advance a single step towards the discovery of the real nature of the mind.

From these considerations we may infer the method of inquiry which must be most fruitful in the natural sciences. The most important truths in those sciences have been discovered neither solely by the analysis of philosophical notions, nor solely by mere observation, but by a combination of reflection with observation: that which was essential has been distinguished from the accidental in the facts observed, and fundamental principles have been thus discovered from which many other phenomena might be deduced. This is more than mere empirical observation; it is philosophical observation.

There are general notions or ideas belonging to all sciences: they are the general truths which are not tangible by the senses, but are abstracted by the mind. These abstract notions are obtained, however,

only by the analysis of observations. In the natural sciences, phenomena are analysed for the sake of forming general notions from them, and of ascertaining the relations of the simple ideas suggested by things. Abstract mental notions, and their relations to each other, are peculiarly the proper subjects of philosophy; and hence this science draws its material from all other sciences, and forms the bond of their union. Although so nearly allied to the philosophical study of some other sciences, yet philosophy is itself a distinct one; since it has to do with abstract notions, which form the basis, not of one science only, but of many,—such as the notions of existence, essence, accident, change, cause, quantity, quality, space, time, matter, spirit, &c. Many general notions,—such as those of force and matter, motion and weight,—belong chiefly to particular sciences; but every science is philosophical as far as it embraces general notions from which phenomena may be deduced.

The mind of man and that of animals compared.—The mental phenomena presented by animals, and by man, agree in several points; while in others they differ. In the minds of both, ideas or mental perceptions are formed from the impressions on the senses, are retained, and are reproduced, and in both association or mutual attraction of ideas, according to definite laws, takes place: but only the human mind is able, from the contemplation of several distinct phenomena, to form a general idea which does not correspond to any one of the single impressions on the sensorium, yet represents the common property of all. Man alone can conceive abstract notions. The only general idea which an animal can conceive, is an image comprehending the most frequent and unchangeable characters of an object of the senses. The difference, therefore, between the human and brute mind may be expressed by saying that the latter is wholly devoid of the λόγος; while on the possession of this depends the entire creative power of the human mind and the faculty of language. The mental operations of animals do not consist of more than the conception of simple ideas, the manifestation of desire, and the association of those ideas which result immediately from impressions on the senses.

Ideas produced by impressions on the senses are associated both in man and animals, according to the principles of resemblance, simultaneous existence in the mind, and succession. But the human mind associates general notions also with the simple ideas or conceptions; passing from the general notion to its particular examples in objects of sense, and from these again to another general notion to which the particular object last conceived belongs.

Animals, it is true, can readily combine two ideas; but, notwithstanding all that has been said concerning their reasoning powers, they are wholly incapable of conceiving a general notion. In these remarks,

we, of course, except all the instinctive phenomena. A dog will gradually become accustomed to perceive that hats and caps of various forms are put upon the head, but will never form the abstract idea of a covering for the head. Something analogous to the conception of abstract notions certainly takes place, as Herbart has remarked, in the case of the simple conception of objects of sense; since the mind does not retain an image of all the details of an object, but merely an undefined image involving its most constant characteristics. In this sense, an animal also may have general ideas. A dog will recognise its master, whether he wear this or that covering on his head, or none at all,—whether he is naked or clothed; in fact, the dog recognises the same object despite its variations in detail, because some main points remain unaltered. Sticks of very various form and appearance will be known by a dog to be sticks, and the idea of blows will be associated with them: but, nevertheless, brutes are incapable of conceiving the higher abstract notions, which are not mere reflections of impressions on the senses, but depend on the reciprocal action of groups of ideas on each other. The dog recognises the same object in spite of its minor variations; but the abstract notions of identity, of the essential, of constancy, as opposed to accident, of difference and of variableness, are beyond the limits of its mental faculties.

The compound mental phenomena of animals may appear well adapted to the desired object, without being attended by any general notions, or being anything more than an association of impressions made on the sensorium through the medium of the senses. A cat, finding the door of the room, which contains its human companions closed, lies down before it until it is opened, and emits its instinctive cry. On several former occasions the door had been opened under these circumstances, and the cat associates the series of acts in its mind; until at length that which is required by the association of ideas really takes place. A keeper of animals has one of his monkeys upon a pole; he wishes to draw it down by means of a string which hangs from it; but the monkey, seeing what his master is about to do, and not wishing to descend, draws up the string with its fore-paws. This act, however, is also the result of previous associations of ideas, just as is the running away of a dog when the stick with which it has been beaten is shown to it; or the sneaking, shamed demeanour of a dog caught in an act which has before been followed by unpleasant consequences.

The association of ideas in the human mind is not a combination of mere simple ideas derived from external impressions according to their resemblance, previous order of succession, or simultaneous occurrence; but with these simple ideas abstract notions become mixed up. From the idea of "blue" there is a transition of the mind to the art of "painting;" from this to "Raphael;" then to the abstract idea of

“beauty;” and next to a particular “beautiful object;” and so on, from the general to the special, and thence to other general notions and other specialities. In the ordinary association of ideas this process takes place unconsciously or indistinctly; but in the act of thought, the general notions, and particular ideas belonging to them, are compared with each other, and applied to the elucidation of each other, the whole being a conscious act.

The desires and passions also exist both in the mind of man and in that of animals, in equal intensity; but the passions of animals have never reference to abstract ideas, but merely to external objects of the senses. The attachment and fidelity of animals are founded in the association of former pleasing impressions with the image of the person whom they follow. Both man and brutes seek what is pleasing, and avoid that which is unpleasant; but men only are affected agreeably and painfully by abstract ideas and thoughts.

From the foregoing considerations it may be inferred that the mind of man and that of other animals are distinguished not by the mere obscurity or lucidity of their conceptions, but by the degree of simplicity or complexity of their ideas, and their reciprocal reaction. The inferior class of conceptions, in which no general notions are formed, may in fact be very distinct; while so far is the formation of an abstract general notion from being merely the very lucid conception of an idea, that, in the act of abstraction, those particulars in a group of ideas which do not agree, seem to obscure or neutralize each other, so as to leave merely the common property as the general notion. The formation of general notions, and the act of thought, are highly complex processes; and hence in sleep and fever, where the brain is not in its normal state, the conception of simple ideas, and their association after the manner of the brute mind, can take place, but the higher faculty of thought is never exercised.

SECTION II.

Of the Mental Phenomena.

THE whole action of the mind consists of the conception of ideas and of emotions; and all the mental phenomena are either ideas or emotions. These, however, differ in themselves, being sometimes simple and sometimes complex; they differ also in their mode of combination, and in their connection with the actions of the body. The conception of ideas, their association and reaction on each other, constitute what is called the “intellect,” or “understanding;” the emotions, both simple and combined, are also termed the “affections,” or “passions.”

CHAPTER I.

OF THE CONCEPTION OF IDEAS.—THE UNDERSTANDING.

An idea or conception is that which is excited in the mind by impressions on the senses, or by those actions of our own body which are communicated to the sensorium. When once excited, the idea remains in the mind for a certain time. It is something corresponding to a distinct impression on an organ of sense, or to the general quality of several such impressions; and it may be regarded as a definite mode of reaction of the mind under the influence of a determinate stimulus. All our ideas belong either to impressions on the senses, and particular states of our body, or to the general notions deduced from the ideas thus obtained, and the relations subsisting between them. The simple conceptions, or ideas of the first kind, are exemplified by the ideas of a blue spot, a particular sound, a known tune, a certain painting, or a particular tree. We have examples of conceptions of the second kind in the general notions of colour, sound, taste, smell, virtue, power, &c. We may therefore make a distinction between simple ideas suggested by impressions on the senses, and the general abstract notions. There are other ideas which are compounded of both these: for instance, it is possible to form the conception of "a man in a particular state of mind."

1. *Simple Ideas suggested by impressions on the Senses.*

What relation does the mental conception, the idea, in these cases, bear to the sensation?—in what relation, for example, does the idea of blue stand to the sensation of blue,—or the idea of a tune to the sensation of hearing it? We know that all impressions on the senses leave an after-sensation frequently of long duration. May not the idea induced by a sensation, and afterwards recalled by memory, be the remains of this after-sensation, merely rendered feeble and indistinct? On this supposition the idea of blue would differ from the sensation of blue only in intensity. But this cannot be: we can easily distinguish the very vivid idea of a colour from the last glimmering remains of the actual sensation; and while gazing at a yellow surface, we can form the idea of a blue one. It appears, therefore, that the conception of an idea is very different from the mere perception of a quality through the medium of an organ of sense. An idea is rather a sign standing for the sensation, but a sign which belongs to a particular sensation and which consequently varies together with the sensation.

This view receives still more support from the fact of our being able to conceive ideas which cannot possibly be the remains of mere sen-

sation, since they represent only the general quality of many sensations, as is the case with the general ideas of "colour" or "sensation." It cannot be said, in reply to this, that no such general ideas of sensations exist, and that in all cases some definite colour, something special, is present to the mind; for in reasoning, and in the act of thought generally, we certainly do distinguish between the abstract notion of colour generally, and the idea of a determinate colour: without this distinction, indeed, it would not be possible to institute any comparison between the general ideas or abstract notions, and that which is comprehended in them.

The idea of an object of sense is, therefore, different in quality from the corresponding sensation; it is something merely conceived in the sensorium; while the sensation is not only presented to the mind, but also perceived in the peculiar quality or "energy" of the organ of sense: the idea is, in fact, as we have already said, merely the sign of the sensation. That ideas can excite the production of images in the organs of sense, is certainly true; this, however, is a complex phenomenon. The idea and the sensation bear about the same relation to one another as a word to the thing it signifies, or as the notes of a tune to the tune itself.

The recognition of an object on its being again presented to an organ of sense by means of the corresponding idea, which has been retained in the mind, and the consequent belief in its identity, prove not merely the similarity of the idea to the sensation produced by the same object, but further, that each sensation always excites a determinate idea, and that the same sensation invariably produces the same idea. If, therefore, the sensation be not preserved, but the idea retained, each renewal of the sensation will be attended with the re-appearance in the same manner of an idea, which, on account of its complete similarity to that excited by the previous sensation, will be regarded as identical with it. And thus written characters call up ideas, although they have not really in themselves anything similar to the object of those ideas.

It is not necessary that the idea of an object having extension in space shall itself have that property. On the contrary, the idea may have the same relation to the object of sense as the expression of a figure in an algebraic equation has to the figure itself, or as the infinitesimals in the differential calculus have to the integrals. Notwithstanding the uncertainty which involves the question whether objects of vision are perceived in the optical apparatus, or in the brain, (see page 1163,) it may yet be supposed that the ideas of objects of sense are always formed in the organ of sense, on which the impressions were originally made, and consequently have the same properties of extension as

those impressions. This view is proposed and illustrated by Henle in a paper "On the Phenomena of Memory in the Senses."* He has founded his remarks principally on the images which present themselves apparently in a visible form, and with the distinctness of reality, when the eyes have some time previously been long engaged in the contemplation of the same objects. These images are different from the mere after-sensations which are left for a certain period of time by a long continued impression on nerves of sense. An anatomist, who during an entire day has been occupied in dissecting the same structures, and has fixed them in his eye, frequently experiences, after the interval of days differently employed, a sudden reappearance before his eyes of those same structures, with distinct outlines, though destitute of light and colour. These appearances will be treated of more fully at a future page. The difference between the perception of an impression on the senses, and the mere idea, which has not the peculiar quality of sensation, appears to be, that, in the former, peculiar states of the nerves—for example, of small points of the retina,—produce simultaneous impressions on the sensorium; and thus exert on the mental image a modifying influence, which does not come into action in the simple conceived idea.

If the idea of an object of sense has been frequently associated with that of a certain sign, however arbitrary and void of analogy, these two ideas will subsequently suggest each other reciprocally, in accordance with the laws of the association of ideas, which will presently be explained: the idea of the object of sense will be always excited whenever the idea of the sign connected with it arises in the mind, and vice versâ. On this depends the use of speech, of the written characters of music, &c. where series of signs suggest innumerable successive ideas of objects of sense.

2. *General ideas or abstract notions.*

These are ideas of a general quality, contained in, or involving several simple ideas. Some ideas of this kind are so little removed from individualities, that they admit of more accurate definition only by reference to the actual sensations; such are the ideas of blueness and redness, which are the abstract ideas deduced from the perception of many red and blue objects, and the idea of colour, which can only be defined as the common quality of many different sensations. These general abstract notions, also, like the simple ideas, become connected with signs, and are suggested by them. It often happens with respect to these general notions, that the ideas popularly associated with their signs are not really those which correspond to their true import. Hence it is that many persons are said to think with words instead of

* In the *Wochenschrift für die gesammte Heilkunde*, 1838. 18.

ideas; and that in some languages there is frequently great difficulty in rendering by correct signs certain abstract and correctly conceived notions.

3. *Process of the conception of ideas. Association of ideas.*

Every idea which arises in the mind retains its distinctness only for a definite and very short space of time. It is quickly supplanted by other ideas, which surpass it in intensity, but which in their turn experience the same fate. When an idea is supplanted in this manner, the mind ceases to be conscious of it; and in no case, indeed, can more than one idea, or several combined together, be present to consciousness at the same time. Something similar to this is observed with respect to the impressions on the senses. When several impressions are made on different senses at the same time, frequently that only is perceived by the sensorium to which the mind is especially directed, and sometimes, in fact, all external impressions cease to be perceived, when the mind is occupied with an idea which has no reference to them.

Ideas, however, which have been once conceived are not wholly lost, though the mind ceases to be conscious of them, but under certain conditions return with all their former intensity, and become again present to the mind.

It may be asked, whether the consciousness which conceives the idea is something distinct from the idea itself; whether it illumines the ideas, as it were; and then leaves them in obscurity, when they cease to be manifest to the mind; or, in other words, whether a vivid idea is merely one towards which consciousness is directed. It is, however, difficult to conceive of a consciousness independent of ideas; even the state of self-consciousness is really the consciousness of an idea. The contrary supposition, namely, that consciousness is merely the presence of a very vivid, that is, an actual idea, appears adequate to explain the phenomena. According to this view, the process of the conception of ideas becomes a more simple one; for we have merely to study the laws according to which ideas become vivid, present to the consciousness, or "actual," by evolution from the chaos of "potential" ideas; while, on the supposition of a consciousness existing distinct from the ideas, there still remains something behind these ideas which requires explanation.* The ideas which are present in the mind, but are not manifest to consciousness, which, in other words, are potential, but not actual, may, therefore, be regarded as latent or quiescent ideas, which mutually restrain and balance each other; while the "actual" idea of which the mind is conscious may be looked upon as a free active idea, or an idea manifesting itself.

* See Herbart, *Lehrbuch der Psychologie*, p. 12, and Stiedenroth, *Psychologie*, p. 50.

When one active idea succeeds another in the mind, the second must either resemble the first; or, if this is not the case, it must have succeeded it in a similar manner on a former occasion, so as to have become combined with it in a more general idea. All these relations resemble each other in an affinity existing between the ideas that are associated. Like attracts like, and so also similar ideas attract each other.* It is a correct and graphic expression, that the motion of ideas is propagated through the connections of resemblance, succession, or previous co-existence, or through the still more simple bond of previous combination.

The active state of an idea consists of an increase in its intensity or lucidity, and a subsequent fading. While this is taking place, the active idea exerts an influence on the mass of latent intelligence, and disturbs its balance, drawing into action those ideas which have an affinity with itself, or, in other words, communicating to them its state of motion or action. The primary idea is itself not persistent; it may be displaced, as soon as a new impression is made on the senses, by the new idea thus excited. If no relation exists between the new idea and sensual impression and the former ones, while the new idea is very distinct, as is always the case with those suggested by impressions on the senses, then the previous idea fades from the mind in proportion as the other becomes more distinct. But even though no new impressions on the senses should excite new mental conceptions, the mind does not remain long occupied by the same idea. For since each active idea exerts an attractive influence on allied ideas which were latent, a series of thoughts soon pass through the mind. From the idea of a tree, for example, I find my mind quickly passing to that of a forest. This, again, suggests the idea of wood, which calls up that of a building; and then the ideas of a marble temple, and a statue, successively pass through the mind. Each link in this chain of conceptions is allied to that which precedes it, as well as to the succeeding one, although the last has no resemblance to the first,—the idea of a marble statue has no affinity to that of a tree. Each new idea, in fact, acts as a new centre of attraction on the mass of latent ideas, while those which preceded it in the state of action are now passive. For an idea to have any permanence in the mind, it is necessary that it should exert its attractive power on the ideas which are still allied to the original idea; as, for example, when the mind passes from the idea of the “whole” to that of a “part,” from this to another “part,” to the relation of “parts” to each other, and from time to time to the original idea of “the whole.” Two similar ideas mutually strengthen each other; while two dissimilar ideas weaken or neutralize each other. Thus a melancholy thought is

* See Hegel, *Encyclopædie*, p. 422. Compare Beneke, *Psychologie*, pp. 32, 72.

rendered more intense by the accession of another similar thought ; but a melancholy thought and a cheerful one meeting in the mind neutralize each other's action ; or if one is in a very active state, so as to call up similar ideas in the mind, then the idea which is opposed to it is reduced to a latent condition.

It is evident, however, that the attraction of ideas is far from explaining the whole process of mental action ; for it by no means renders intelligible why, during the rise into activity of the new or attracted idea, the preceding or attracting idea should become latent. If the whole action of ideas consisted in a kind of attraction, they would form aggregates ; and each new attraction would be the action, not of the idea last excited only, but of the whole aggregate of similar ideas already called up in the mind. If the attempt is made of fixing an idea in the mind while light and sound, and all impressions on the senses, are excluded, it will be found quite impossible to do so. In spite of the greatest effort to keep the idea "bird" fixed in the mind, another allied idea—such as that of "Pegasus"—will soon present itself: then perhaps the idea of "poetry" will follow, and in succession those of "Homer," "Achilles," "tendo Achillis," "Myology," "Albinus," and so on. It appears, therefore, that besides the attraction of similar ideas, there is something in the action of the mind which causes the active state of each idea to cease after a period, just as in the progressive undulations or vibrations of bodies, the motion ceases in the body which excited the progressive undulations in other bodies, even before it has passed through the conducting chain with which it is continuous. In the motion of undulations, the force which induces the state of rest is the tendency to the physical equilibrium. No such physical agency can be supposed to limit the duration of ideas. It appears, however, that there is an analogous tendency to equilibrium in the latent ideas of the mind ; in consequence of which, the disturbance, produced by the tension of a single idea, is soon restored. The duration of the active state of an idea accordingly depends on the time required for its reduction to a state of equilibrium. The motion of the idea which was in the state of tension has, in the mean time, extended to another idea which was inactive, but which is now thrown into tension. The duration of an idea depends therefore on the intensity of its motion.

The association of ideas, then, may be compared to a progressive motion ; the state of tension passes over the ideas which were in a state of rest or equilibrium ; and the different ideas are successively thrown, like the particles of matter affected by a wave, from a minimum into a maximum, and again into a minimum of motion. This, of course, is intended merely as a figurative description derived from physical phenomena. The progressive tension of different ideas is the wave ; and the ideas which successively arise in the mind, and disappear from

it, are compared to the different particles which are in turn affected by the vibrations of the wave, and left at rest behind it.

Allied ideas alone succeed each other in the mind, or become successively thrown into the state of tension. All those latent ideas which are dissimilar to the present active idea, or are indifferent in relation to it, remain unaffected. Each succeeding idea is, however, neither absolutely identical, nor absolutely different from that which precedes it: the two are, in some respects, similar, in others dissimilar; as, for example, are the ideas of a "leaf" and a "tree," those of "genus" and "species," those of "Achilles" and "tendo Achillis," or those of "sea" and "fish." The ideas which succeed each other are allied in their purport, or in part similar; or if, in themselves, quite dissimilar, they are allied in the relation of coexistence in a previous impression on the senses, or in that of previous succession.

The ideas of objects existing in the same landscape mutually suggest each other; and in the same way the successive occurrences of a former journey are easily recalled to mind. Even contrasted ideas are not excluded from mental association; for they are in some measure allied. The ideas of very small and very large things are readily associated in the mind; for they are relative ideas. The ideas of great and small, and of light and dark, are, in fact, so nearly allied, that it is often impossible to distinguish between that which is great and that which is small, or between that which is light, and that which is dark, when they are not actually compared.

Since each idea is allied to many others, and yet is followed in the act of association by one only of these allied ideas, we must seek the cause determining the particular idea excited, in the different degrees of disposition to tension of the different allied ideas which are latent. Ideas which were in an active state on the previous day, and have frequently been so, are roused again to activity by a less strong affinity than ideas rarely present to the mind, and long undisturbed. Hence it appears that even latent ideas cannot be regarded as in a state of complete equilibrium. In fact, they do not merely form the latent materials of the understanding, from which the active ideas are derived, and to which they are again reduced by the tendency to equilibrium; but they undergo even in this latent state slight and indistinct movements. Though not drawn into the field of actual thought, they yet are so far affected by the tension of other active ideas as to be themselves thrown into a disposition to tension when those ideas are allied to themselves. Sometimes, indeed, we can perceive that an indistinct shadowy idea accompanies other vivid ideas, and seems to be striving to become active and manifest. We have indistinct remembrances of persons and things.

From the foregoing considerations, we may safely affirm that every idea in the state of activity, — that is, in the state of freedom or development from the general equilibrium, — is capable of throwing another allied idea into the same state of activity; but that, while it does this, it becomes itself inactive or latent. The return of an active idea to its latent state is completed very gradually, and not until a long series of other ideas have passed through the mind. The proof of this lies in the fact of our being able to recall very readily ideas which have a short time previously been present to our consciousness. Whether the current of our ideas ever entirely ceases for a period during the waking state, is doubtful. We sometimes, indeed, seem to be in so passive a condition as to have no ideas present in the mind: but even here there may be one idea in the active state; namely, that of our freedom from thought. There is, however, nothing unreasonable in the supposition that during sleep, when all external impressions are excluded, a completely inactive state of all our ideas may ensue for a certain period. There is a difference, too, in the rapidity with which ideas succeed each other, not only in the minds of different persons, but also in the mind of the same person under different circumstances. Exercise of the intellect, and many states of the body, fever, nervous irritation, a certain stage of narcotism, and wakefulness, make the succession of ideas more rapid; while the taking of food, or spirituous liquors in excess, inactivity of body, and sleep, render the current of the thoughts perceptibly sluggish.

In the lower grade of intellectual operations, of which even animals are capable, the act of association is confined to ideas of objects which have formerly been presented to the senses at the same time, or of which the ideas have previously succeeded each other: but abstract notions are also ideas, and are also associated with other ideas, even with those of particular objects. An individual thing which has undergone a change, may give rise to the association of the general notion of change, and this to the general notion of motion, which bears to that of change the relation of species to a genus. A large object calls to mind the general notion of size; the idea of a very large object excites that of infinite size; the idea of a small object that of infinite minuteness; the permanence of one quality, while many others are varying, suggests the general notion of something essential, and this the contrary one of an accidental quality, and so on. In this association of general notions, the relations of succession as to time, and co-existence as to place, remain quite subordinate. The interchange of ideas here consists rather in a constant expansion and contraction of the conception; the mind being alternately occupied by a particular idea, and by the general notion to which it belongs,—as, for example,

in the following series :—Narcissus, flowers, plant, organic being, animal, elephant, ivory, art, painting, brush, hair, horn, wart, cicatrix, inflammation, and so on.

In reading, two series of ideas accompany each other,—namely, the ideas of the signs, and those of the things indicated by the signs,—the ideas of each series being associated more closely with each other than with those of the other series. When that which is read is also spoken aloud at the same time, a third series of ideas accompanies the others; and the same is the case in the execution of music from notes. In such a complicated mechanism as this, where ideas of signs are constantly alternating with general notions and ideas of particularities, the act of connecting the ideas with each other must naturally be rendered difficult in proportion to the frequency with which the ideas of the signs interrupt the chain of the ideas indicated. Hence, in reading, we frequently find ourselves associating with perfect correctness the ideas with the signs, though without any comprehension of the connection of the ideas amongst themselves.

When the idea of anything is reduced to equilibrium with the other latent ideas of the mind, the thing is “forgotten.” The “recollection” of it depends on the idea being again called into an active state from its state of equilibrium. It results from the foregoing considerations that there is no special faculty of “memory.” No idea is ever lost; and every act of the mind, by which latent ideas are rendered active by association, is memory.

In proportion as an individual loses the power of vivid association of ideas, he loses his memory. The kind of memory which a person possesses is therefore different, according to his capability of associating merely the simple ideas corresponding to impressions on the senses, or the higher abstract general notions. Many persons have a great memory for words, sentences, language, for the succession and coexistence of particular things and circumstances, without having, in a perfect degree, the faculty of remembering general notions and their connections, and without possessing great intellectual powers. This arises from their minds being chiefly active in the association of particularities. In other persons all ideas are prone to call up general notions which draw their minds away from the series of successive or coexistent particularities, and lead them to abstract speculations. These persons, consequently, are deficient in the memory of individualities, but may have in perfection the power of recollecting the relations of ideas according to general notions.

We are able to give a determinate direction to the association of our ideas, and thus to direct our memory. When I call to mind the occurrences of a journey, I can at will cause the ideas of past circumstances to succeed each other in the retrograde course, from the close

of the journey to its commencement. In this case the association is subject to a distinct predominant idea, that of the reversed succession. The direction of the association is, therefore, properly the result of necessity, not of volition; for the main ruling idea being given, the rest must follow in accordance with it. The direction once determined remains the same, until the ruling idea is reduced to the state of equilibrium. Thus I can determine my own mind to the conception, during a certain period of time, of a number of opposites, such as white and black, essence and accident, infinite and finite, small and great, internal and external, and so on. In this way, also, we endeavour to recollect a particular thing. Frequently we do not succeed, because the idea which we seek—for example, the word corresponding to an abstract notion—does not lie in the direction of the idea taken as the guide to it. Sometimes, also, the idea which is sought presents itself very obscurely to the mind, and we perceive that it is very near, but cannot obtain perfect distinctness; or we perceive that the word that is sought exists in the mind, although it is defective from a part of its sound or letters being kept in a latent condition, or state of equilibrium, by a contrary idea. Sometimes we succeed better in recollecting what we desire by talking or thinking of indifferent things, amongst which an idea may occur adapted to suggest the one which is sought. Even when it is determined to retain something in the memory, and to execute it at a particular time, the ideas are placed under the rule of a leading idea, and led back from time to time, even though by long circuits, to the original theme.

Imagination, or the production of new ideas, differs from the ordinary reproductive association in its free metamorphosis of the images or ideas called up into the mind, beyond the limits prescribed in mere recollection. This productive, Protean property of the active idea may be best observed in the dark of evening. In bright daylight the strictly normal character of the impressions on the senses interferes with the creative action of the mind. But if in the dark we picture to ourselves a face, it generally does not long retain its original form, but undergoes various transformations, often with fearful distinctness; and the forms which are thus produced are by no means such as have previously been presented to the mind through the medium of the senses, but are new and surprising combinations. It has often been a subject of dispute whether the fancy is able to form anything entirely new. That the elements of all the images of fancy are derived from ideas obtained by experience, is certain; but the modification and combination of these elements into new products, appears to be wholly in the power of the imagination. In the unilluminated field of vision, the imagination traces all varieties of outlines; and as forms are determined by their outlines, such forms are of course in this way produced as never really existed. A mind

which is less imaginative will merely combine images previously presented to the mind by the senses; thus it will unite the wing of a bird to the shoulder of a horse, or the tail of a fish with the body of a quadruped. But the more creative mind will not only combine the images previously derived from without, but will also modify these, expand them, and transform them. When Goethe with closed eyes pictured to himself a flower, this image, as he himself relates, underwent the most remarkable changes: new leaves of new forms were developed from it, and it metamorphosed itself into the most various figures, though with a certain regularity and symmetry.

4. *Thought or reasoning.*

The first step in the process of thought is the formation of general notions, or the act of abstraction. The mere association of ideas and their replacement one by another, is a much more simple process than that of their mutual reaction on each other; and hence the act of imaginative association is less difficult than that of forming abstract ideas. When two or more different ideas are present together in the mind, they neutralize each other in those respects in which they differ, and there remains only that part of them in which they agree. But this, their common quality, acquires an increased intensity; for similar things strengthen each other. From this kind of abstraction to the act of reasoning there is but a step; and reasoning is only a higher grade of intellectual association. The conceptions are here not mere simple ideas alternating with each other and with general notions, but ideas of relation. Thoughts are ideas of relation subsisting between two or more ideas. The action of the mind in its most simple form consists merely in the constant transition from one thing to another. In this simple association the ideas succeed each other like the series a, b, c, d, e, without the relation which they bear to each other becoming the subject of consciousness; but in thought the mutual relation of the ideas, as a : b : c : d : e : is perceived by the mind as well as the ideas themselves. Even a chain of associated ideas, in which general notions mingle themselves with simple ideas, such as the succession of candle, light, blue, optics, acoustics, waves, sea, depth, infinity, does not amount to thought. For here the copula of the simple ideas and general notions, namely, the law of the attraction of like for like, passes through the mind unperceived; and only the copulate or associated ideas are the subjects of consciousness: for we do not in such a train of ideas have the distinct conception that blue *is* light, and that the sea *is* deep. But in the process of reasoning, the copula, *is*, becomes itself a conscious conception of the mind. Every thought, therefore, involves at least three ideas, two of which are united by the third, or the idea of the copula.

The simplest copula is the idea of identity or similarity, and is expressed by the word *is*. The purport of the one idea either is entirely the same as that of the other, or is equal to only a part of it. In either case the copula is expressed by *is*.

The first case may be represented by $A = A$. A particular thing is identical with itself; or two things, a and b , are so similar, that they must be regarded as identical, which may be expressed thus: $a = b$, or $a : b = a : a$.

In the second case just referred to, one idea is only a part of the other, as *ultramarine is blue*, *sounds are vibrations*. All vibrations are not sounds: this thought is, therefore, not correctly expressed by the sign $a = a$; on the contrary, the thought, *sounds are vibrations*, corresponds exactly to the thought, *in 4, $\frac{1}{4}$ or $\frac{1}{a}$ is contained*. If we represent sounds by a , and vibrations by b , the formula for the proposition will be, $a = b + x$, or *sounds are equal to vibrations and something besides*, or $a = b \times y$, or $\frac{a}{y} = b$, by which we express that the one idea comprehends only a part of that which the other involves.

In most thoughts *is*, or the idea of entire or partial identity, forms the copula. But any idea of relation may serve to connect the two other ideas. Combinations of simple ideas with general abstract ideas by means of another abstract idea, as in the foregoing examples, are *propositions*. But when two such thoughts or propositions are placed in the same relation to each other by the recognition of identity, or by the idea of partial similarity, as the two principal ideas in each simple proposition, they constitute a *conclusion* or *syllogism*, the formula of which is, $x = a$, and $y = x$, consequently $y = a$.

Besides these most general forms of thought, there are a number of abstract notions which enter as accessory ideas into our propositions and conclusions, and which in language are expressed by the particles. They serve to indicate the modality of the propositions and conclusions, their connection and relations.

5. Self-consciousness.

In addition to the conceptions of the relations existing between ideas, our mind conceives ideas of the external world and of the subject or self which is the seat of the mental conceptions. These ideas have their source in our organic appetites for external things which seem to supply that in which we are deficient; but they are rendered more defined and distinct by our experience of the difference between our sentient body and the external world, which is the cause of its sensations, and which reacts against its actions. The circumstance also of the different parts of our own body being constantly present to our senses amidst all the changes of the external world, leads us to recognise this object, which remains constantly the same, as our own

body ; for we perceive that it varies only according to our will, while all other objects change independently of us. Our spontaneous actions, which are attended with sensations, also leave ideas in our mind, and we learn to distinguish the ideas of these actions from the mass of ideas of other things. Thus arises the idea of independent life. The abstract notion of all which belongs to this independent life is the “Ego,” or “self.” This is the idea of that general point of resemblance in all our different actions, which remains when their various differences have neutralised each other. The conception of our “self” being the source of ideas, or the conception of ideas being qualities or particular states of our “self,” is what is called “self-consciousness.” This is evidently an acquired, not a primary or original idea. Moreover, it is at first impossible to distinguish whether the sensations and ideas, when originally produced, belong to the absolutely external object, or to the object which we learn to recognise as our own body.

6. *Feelings.*

The significations of the word “feelings” are so manifold, both in ordinary language and in psychology, that it is unsafe to employ it. By the feelings are sometimes meant the painful and pleasing, and other allied, emotions of the mind ; sometimes states of the mind wholly devoid of the character of passion or emotion, such as the feeling of truth, and the feeling of presentiment, which are rather ideas only indistinctly conceived. At other times, again, the same word is applied to express certain ruling or predominant ideas, such as the feeling or sense of honour, moral feeling, and the feeling of propriety.

Some psychologists confound all these different states of the mind, although all pleasurable and painful feelings are merely particular states of the “subject” or “self” and of its “strivings” ; while the moral feeling, the æsthetic feeling, &c. have reference to true “objective” relations. Most states of the mind belong to the category of ideas. It is very desirable to distinguish particular relations of these ideas to each other by particular names. The words *thought*, *abstract notion*, and *proposition*, serve this purpose ; and the word “feeling,” also, might be applied to a particular mode or relation of conceived ideas, had it not unfortunately been employed to designate totally different states.

The painful and pleasurable feelings, and the numerous allied states of the mind, will come under consideration in the next chapter, for they are conscious states of desire.

Those “feelings” which are really ruling predominant ideas, notions, or propositions acquired by education, such as the moral feeling, feeling of honour, the æsthetic feeling, the feeling of propriety, &c. and the erroneous modifications of those ideas which are called prejudices, differ

from other ideas, abstract notions, and propositions, only in their capability of a practical application to the relations of mankind, and consequent adoption as a standard of right. The majority of numerous other so-called "feelings" are nothing more than unconnected, and consequently indistinct, masses of ideas which float before the mind, such as the feelings of "presentiment" or "misgiving."

CHAPTER II.

OF THE PASSIONS, AND OF THE DISPOSITION.

Many ideas are accompanied by a state of the mind which is something distinct from the idea itself, and is what we call emotion. If pain is felt, and the idea of it is conceived in the mind, it excites an adverse mental emotion or striving against the idea. Even the mere idea of pain or pleasure gives rise to emotion. Everything opposed to this striving of the mind excites painful feelings; everything which favours it, feelings of pleasure. The mind, therefore, is susceptible of another state besides the conception of ideas; and the exaltation of this state produces, not increased lucidity and distinctness of an idea, but the aggravation of an emotion. The object of these emotions or strivings of the mind is not merely to avoid pain, and the ideas of pain, and to obtain pleasure, and ideas of pleasure, but also to maintain a certain power of individual existence, and to resist a diminution of that power. The striving of the mind in its most general sense is the effort to maintain the existence of self, and to extend its power of action. Everything which opposes or restricts this power, gives pain; everything which favours or extends it, causes pleasure. The objects may vary, but the mental striving remains. That which is conceived to be opposed to the striving of the mind to-day, will on the morrow be indifferent to it, or even favourable. The objects of the mental emotion are, therefore, different at different times; but they are always those which at the time are adequate to restore the natural condition of the mind, or to increase its power.

Emotion is constantly combined with ideas. The emotion itself, and the sensations and actions which it causes in the body, are conceived by the mind, as well as the things which are the objects of the emotion. The idea of self, and of individual existence, is the fundamental theme of all the ideas combined with emotions; but the idea of self, and of a change suffered by it, does not, without the state of striving in the mind, constitute passion. Thus the idea of the present state of self, as compared with the former state, when it is $A - a$, does not constitute sadness; and when it is $A + a$, does not amount to joy. In order to produce a passion of the mind, the state of emotion or of striving against ideas which oppose it, or with ideas which favour it, is required.

On the other hand, however, only such ideas as have reference to self are capable of exciting passion.

As long as the changes which are the subjects of our contemplation have no reference to ourselves, nor to other beings allied to our feeling of self, the ideas which they suggest pass through our mind unaccompanied by passion; they are not unpleasant to us, and excite neither sadness nor desires. But as soon as the idea of self, of the restriction or extension of the power of our self by the conceived idea, comes into play, then the passion of sadness or joy, or the striving for the preservation of self, or for the increase of its power, arises in the mind; there is then a striving to restore the integrity of self which the mind has conceived to be subjected to diminution or subtraction of power. The feeling of self is, therefore, an element of all passions. It is true, we enter into passionate disputes concerning mere opinions when the *meum* and *tuum* are not directly indicated; but, even in this case, the opinions concerning which we differ, have by habit, education, or accident, become identified with ourselves, and in the mind constitute, as it were, a part of ourselves. We also become the subject of passions on account of others, and of accidents which occur to others; but this happens only when our feeling of self is interested, in consequence of the resemblance of others to ourselves and of our own self being implicated in their fate. A controversy concerning opinions loses all its character of passion and restricts itself to the mere objects of dispute as soon as we are able to contemplate those objects without any reference to our individual self. If, when we are engaged in a particular inquiry, we have long followed one opinion, and then meet with a fact which proves the falsity of this opinion, which we have long cherished, we experience an unpleasant or painful feeling, because the opinion thus refuted has already begun to form a part of our own self. Regarded in itself, an opinion not expressed, but silently conceived and silently relinquished, should leave us indifferent to it, and truth indeed ought alone to be pleasing to us; but yet it is universally experienced that an opinion which has long been cherished, when found to be erroneous, becomes a cause of sadness. It is not until the new fact, which proves the incorrectness of the previous opinion, has been frequently contemplated, and has in its turn become, as it were, a part of our self, that the equilibrium of our feelings is restored.

All our passions may be referred to pleasure, to pain or unpleasant feeling, or to desire. In all may be recognised, as elements, the idea of self or individual existence; the idea of the power opposed to self, limiting its power of action or increasing it; the striving to maintain the integrity of self; and the power opposing or favouring that striving of the mind.

In considering the relation subsisting between the passions on the one hand, and organisation and the brain on the other, the first thing to be

observed is, the fact (which I have already many times insisted on), that the process of organisation is antecedent to mental action, and is the means of rendering possible the manifestation of the mind by producing the peculiar structure of the brain. The conception of ideas, and the affections or emotions, do not, however, stand in the same relation to the brain. There is an unconscious striving of the organism which has not its seat solely in the brain. In all organic bodies there is a tendency towards the exterior, and an effort to preserve their own integrity. Even plants are the subject of such a striving during their growth; and in the same sense has the striving even in man a much wider basis than the brain, and is an action manifesting itself throughout the whole organism, and determining the process of organisation. In animals, however, this organic *appetitus* is reflected in the sensorium, and is perceived by the intelligent being which distinguishes between the ideas belonging to the external world, and those referring to self. It is there felt as an obscure power of the individual declaring itself in the manner of an instinct,—as a power which affirms itself constantly, and derives sustenance from all ideas connected with the self or individual being, finding in them causes of restriction and extension of its sphere of action. There are no absolute proofs that these reflections of the striving power are not received and collected in a particular part of the brain of which the structure is adapted for the purpose; in other words, that there is not a region set apart for the affections: but, on the other hand, there is a total absence of facts which might render it probable that organs are set apart for the different appetites, and, at all events, only one identical appetite, one original striving for the maintenance of the integrity and extension of the power of self, exists. This one striving or *appetitus* has different objects, and the direction of its action is determined by the organic conditions of those organs which afford specific modes of intercourse with the external world.*

Mere changes in the state of the body are sufficient to increase or diminish the disposition to different passions, joy, sadness, or desire. The passions and desires of love are sometimes not excited when an adequate external cause is present on account of the organism being at the time little disposed to sympathetic action and excitement; while a trifling external cause very easily produces them if the nervous system and generative organs are in a state of organic tension. A passion or feeling,—such as confidence, candour, or friendship, which may not exist while a person is fasting,—may be experienced when the organic tension has undergone a change. Hence we see that the power or degree of the organic tension predisposing to the mental striving, de-

* See a further reference to Gall's doctrines at page 835,* or page 837 of the first edition.

termines the intensity of the idea relating to self which happens to be present to the mind, and gives to it its impulse or violence. An excessive degree of excitability of the organic conditions compensates for deficient power of the exciting cause, and *vice versâ*, so as to produce an equal result, an equal *quantum* of passion.

The emotions of the mind, on the other hand, produce organic effects in many or most parts of the organism. Even ideas devoid of any accompanying emotion, when of sufficient intensity, excite particular phenomena in other parts than the brain, namely, in the organs of sense, and in the muscles, as is evinced by the "visions" or "phantasms" and by the motions which may be excited by the idea of a motion, such as yawning (see page 932). But the effects of the emotions upon the organism are proportionally much stronger and more extensive.

Everything opposed to the striving of self to maintain its integrity produces a depressing effect upon the mental power and the corporeal actions, painful sensations and impeded movements; everything which favours that striving of the mind has, on the contrary, an exciting influence upon sensation and motion; and in both cases the processes of nutrition and secretion are modified. The organic influence is communicated to the body from the brain. It extends in all directions along the course of the nerves, and produces stronger local effects according to the different dispositions of the individuals. The effects are greatest in those organs which realise the conceived objects of the passion: thus they are strongest in the sexual organs, when the passion is that of love, and in the digestive organs, when the appetite for food is the one present. It must not, however, be hence supposed that the different passions have their seat in the different peripheral organs. These organs play no part in the passions, further than when excited during the prevalence of emotions they react on the brain and on the organic states of the body. In those passions in which the fulfilment of the desires is not attained by means of special organs, the organic effects of the passions extend very generally through the nervous system, modifying the movements, sensations, and nutritive processes,—elevating and increasing their energy in the exciting passions, and depressing them in the depressing passions. A person who is the subject of a particular local idiosyncrasy, experiences the exciting or depressing effect principally in the affected organ; for example, in the liver, in the heart, in the intestinal canal, or in the system of the spinal cord.*

The fundamental emotion of sadness has for its object the idea of something painful; the fundamental emotion of joy, from comfort up to open rejoicing, has for its object the idea of something pleasant. The painful something is in the simplest case, and generally in animals, a painful corporeal sensation. The diminution or restriction of the free

* See page 816*, or page 818 of the first edition; also page 933.

power of self arising thence is sadness. When ideas take the place of sensations, the unpleasant or painful object of the passion of sadness is the idea of a painful sensation without the reality of the sensation; and even the idea causes sadness, and in its turn excites really unpleasant and painful sensations. Every idea, however, even though having no reference to pain, if it involves a constraint of the power of self, is painful, and excites sadness, $A-a$. The constraint or subtraction of something from the feeling of self, A , by the idea $A-a$, is sadness. As long as the feeling of self is not reduced to the same level, $A-a$, the sadness continues, and is renewed each time that the idea A recurs to the mind, if the cause, $-a$, is not removed. But when the equilibrium has been restored, that which was painful to the mind has lost its sting, and hence it is that mental afflictions are cured by time. The simplest kind of pleasure, and that ordinarily felt by animals, is produced by the corporeal sensation of ease and pleasurable feelings, and by the freedom of our corporeal actions; and the mere idea of these physical states is pleasing. In general, however, we derive pleasure from all ideas which seem to extend the sphere of action of our self, and which removes an obstacle to its free play, $A+a$. This emotion or striving of the mind, accompanied by the expansion of the feeling of self from A to $A+a$, is ease and joy: it continues until the equilibrium is restored between A and $A+a$. When this latter change has taken place, the idea a has no longer any influence in exciting emotions, unless the idea A enters the mind, and is again converted into that of $A+a$.

The conception of a pleasure, of which we are not in possession, excites desire. Desire consists in two different ideas respecting the state of our self being thrown into tension as opposed to each other, while the immediate restoration of the equilibrium between them is not possible. The idea of the thing desired is a ; the idea of the actual state of our self is $A-a$; and the idea of the possible state of our self is $A+a$. We strive or desire to bring these two ideas into equilibrium, but an impediment maintains the state of tension. This tension between the ideas $A-a$ and $A+a$, arising from the striving of the mind, constitutes desire, which differs from joy in that the two ideas $A-a$ and $A+a$ are not converted one into the other, but balance each other, the idea $A-a$ exciting the idea $A+a$, and on the other hand the idea $A+a$ that of $A-a$. As soon as the actual state of self is enabled to expand from $A-a$ to A and $A+a$, the state of desire becomes joy, which in this case is called satisfaction. The tension between the actual state of self, $A-a$, and the state A , is the striving to remove something which diminishes the power of self: the tension between $A-a$ and $A+a$ is the striving to obtain that which shall increase the power, or expand the feeling, of self.

The influence of the passions is apt to render our ideas respecting the

relations of external things inaccurate. As soon as ideas of external things, or even truths and opinions, are conceived by us to have a relation to the integrity or power of our self, so soon, as will appear from the preceding paragraphs, are we thrown into the condition which fits us for regarding them with feelings of passion. Opinions respecting external things thus regarded acquire such an intensity as to be incapable of refutation by reasoning. In itself no idea relating to external things is ever in this sense intense or strong, but merely distinct or indistinct, and convincing in different degrees. By intensity or strength of opinions, therefore, we here mean only the power or quantity which they acquire, through the influence of passion, in the consciousness of the striving self. The greater the uneasiness which an unpleasant idea excites, the more capable does this idea become of calling up other allied ideas. The passion which the unpleasant idea produces renders it still more unpleasant or painful, while the idea itself, in its turn, increases the strength of the passion. While therefore the mind alternately regards the idea of the disturbing circumstance, and the idea of its own disturbed state, the idea of the unpleasant nature of that circumstance must increase to an inadequate degree, and thus become incapable of being neutralised by contrary reasons, or of being corrected. Hence it is often impossible to convince a person under the influence of passion of the true nature of external circumstances, except by previously quieting the state of passion, or, in other words, by freeing the mind from the restriction under which the feeling of self is labouring, or from the too great expansion which has been given to that feeling. This is effected most easily in an indirect manner; for everything which is capable of expanding the feeling of self, whatever be its nature, will quiet the passion arising from the idea of the restriction of self. When passion is calmed, the accompanying ideas lose their unnatural intensity and become subject to the simple equilibrium of contrary ideas or opposite reasons. An opinion which acquired intensity from passion may therefore be neutralised or supplanted by an opposite opinion similarly exalted. If a person is unpleasant to us, and we on that account, and without other sufficient grounds, entertain a bad opinion of him, and dislike or hate him, a pleasure afforded us by this person, if sufficiently great, will completely remove our prejudice, by causing us, with no better reason, to approve him. Here one idea rendered intense by passion, is dispelled by another of similar intensity. The jealousy of lovers affords us examples of opinions which acquire even a ridiculous degree of intensity from being attended with passion. The passions take part in the most noble as well as in the most base efforts of men, and communicate to the ideas that intensity which is necessary in the transactions of life, for the carrying out of preconceived resolves, for absolutism, and for the revolution of existing conditions. Mere opinions

concerning the manner of life, nature, or religion, which have been cherished, and become a part of men's selves, are adduced by them, when under the influence of passion, as truths. Mysticism consists in a similar one-sided direction of the ideas, and disregard of what is correct in the opposite ideas; those ideas only concerning religion being followed which are pleasing to the self of the believer, while those are avoided and hated which are displeasing. The correctness of the ideas is here neutralised by their intensity. Fanaticism is of similar nature, but is more active in its effects.

In the foregoing pages we have elucidated the physiological nature of the passions, as far as it is at present known. With respect to their statical relations to each other, it is impossible to say anything that shall excel the masterly exposition given of them by Spinoza. I shall therefore extract those of his aphorisms which relate to this subject. It must be remarked that they merely express the law which would prevail in the mind of a man supposed to be under the entire influence of the passions, and that this law will of course be modified by the human reason.

*Aphorisms of Spinoza respecting the statics of the mental emotions or passions.**

The mind seeks as far as is possible those conceptions which increase or extend the power of action of the body.

The mind, when it conceives an idea which diminishes or limits the power of action of the body, strives to recall other ideas by which the former shall be excluded. Hence it follows that the mind opposes the conception of ideas which diminish or limit the power of action of itself and of the body.

If the mind has been at any time excited by two passions or emotions simultaneously, the presence of one of these emotions will at all subsequent periods cause the other to arise in the mind.

Anything may be the accidental cause of *pleasure*, of *unpleasant feelings*, or of *desire*. If the mind has been excited simultaneously by two contrary emotions, namely, by an idea which gives pleasure, and by one which produces an unpleasant feeling, the return of one of these emotions at a future period will recall the contrary one. The first idea in this case will be the accidental cause of pleasurable or painful emotions.

Hence the mere circumstance of our having regarded a thing with pleasant or with unpleasant feelings of which it is itself not the efficient cause, will cause us to *love* or to *hate* that thing. And hence it follows also, that our merely conceiving that a thing bears a resemblance to an object which the mind is accustomed to regard with pleasant or with unpleasant feelings, will cause us to love or to hate that thing, although its point of resemblance to the object in question is not itself the cause which excites the emotions of pleasure or displeasure.

When we conceive the idea that a thing which is accustomed to fill our mind with an unpleasant emotion bears a resemblance to another thing which always excites in us as strong a feeling of pleasure, we shall love and hate that thing at the same time. This wavering in the feelings is the same thing as doubt in the intellectual operations.

The idea of anything past or future excites in the mind the same emotions, pleasant

* Ethik, 3ter Theil. [For an account of Spinoza's views, see Bayle's Historical and Critical Dictionary, art. "Spinoza;" and Hallam's Introduction to the Literature of Europe, vol. iv. p. 243—263.]

or unpleasant, as the idea of a thing which is present. For the idea, considered in itself alone, remains the same, whether it concerns the past or future.

From the preceding truths, we may deduce the nature of hope, fear, confidence, despair, joy, and sadness. *Hope* is an inconstant feeling of pleasure, arising out of the idea of a future or past thing, concerning the result of which we are in doubt. *Fear*, on the contrary, is an inconstant feeling of something painful or unpleasant in the mind, also excited by the idea of a doubtful circumstance. If the state of doubt is removed while these emotions exist in the mind, the hope becomes *confidence*, and the fear *despair*; or, in other words, constant feelings of pleasure or pain arise in the mind respecting the same thing which has been the object of hope or of fear.

Joy is the feeling of pleasure induced by an idea of a past thing, respecting the result of which we had been in doubt; and *sorrow* or *sadness* is the very opposite of joy.

If any one conceives that the thing which he loves is about to be destroyed, he will feel pain: but if, on the contrary, he conceives that its existence continues, he will experience pleasure. For whatever excludes the presence of the thing which is loved, limits or impedes the efforts of the mind to maintain the state of pleasure.

If any one conceives that what he hates is about to be destroyed, he will have pleasure. For the mind strives after those ideas which exclude the presence of things capable of diminishing the power of action of the body.

Whoever conceives that the being he loves is filled with pleasant or unpleasant feelings, will himself be filled with similar feelings,—*pity* and *sympathy*. For ideas of things which presuppose the presence of that which is loved, strengthen the mind in its endeavours to have present to it the conception of the loved thing itself; and *vice versa*. This feeling of pleasure presupposes, however, the presence of the thing which experiences pleasure, and is an affirmation and perfection of that which is loved. Hence it further follows, that if we conceive that the thing which we love is filled with pleasure by any person, we shall ourselves be filled with love towards that person: while, on the other hand, if we have the idea that he fills it with unpleasant feelings, we shall experience the feeling of hate towards him,—*approbation* and *repugnance*.

When any one conceives that the object of his aversion is experiencing unpleasant feelings, he will feel pleasure, and will feel pain if that which he hates appears to his mind to be experiencing pleasure,—*malicious joy* and *envy*. For as far as the hated thing is filled with unpleasant emotions, it is destroyed, and we are desirous of excluding the presence of those things which exclude ourselves.

When we conceive the idea that any person fills with pleasure that which we hate, we become filled with hate towards him likewise: but if we conceive that he fills the same thing with painful feelings, we are moved with love towards him.

We strive to affirm whatever, according to our conceptions, fills ourselves, or that which we love, with pleasure; and, on the other hand, we have an impulse to deny everything which, as we conceive, fills us or that which we love with pain,—*extravagant pride*, *self-deception*, *over-rating of friends and lovers*.

Inasmuch as we are *proud*, from a visionary conception of ourselves, we are able to effect everything which we can attain by the mere idea.

We endeavour to affirm everything which we conceive to give pain to that which we hate, and to deny whatever we conceive to fill the same object of our hate with pleasure,—*contempt*, *vilification*, and *detraction*.

The idea that a thing similar to ourselves, concerning which we as yet experience no emotion, is affected by a mental emotion, will excite in our own mind a similar emotion,—*sympathy*, *pity*. For this idea suggests the other idea that we may ourselves be exposed to this emotion.

The idea that a person, with reference to whom we have experienced no emotion,

fills with pleasure a thing which bears resemblance to ourselves, will cause us to feel love towards him. On the contrary, the idea that a person fills such a thing with unpleasant feelings, will cause us to hate him.

We cannot hate the object of our pity on account of its causing us pain ; for if we could feel hate towards it on that account, then we should have pleasure in its suffering : while pity consists in pain being felt on account of the pain suffered by our like.

We shall rather endeavour, to the utmost of our power, to free that which we pity from its suffering. For thereby we shall remove our own suffering and that which is opposed to our own existence,—*benevolence, generosity*.

We strive to bring to pass whatever we conceive to lead to pleasure, but endeavour to rid ourselves of and to destroy everything which opposes us and induces pain or unpleasant feelings.

We also strive to do all those things which we believe to be regarded with pleasure by men similar to ourselves ; but, on the other hand, avoid doing what, in our conceptions, is avoided by them. For pleasure and unpleasant feelings are excited in our minds by the knowledge that others regard us with pleasure or pain,—*desire to please, affability*.

When we give praise, we affirm the fact which excites in us pleasure.

When a person has done something which he conceives will fill his like with pleasure, he himself will be filled with the feeling of pleasure combined with the idea of himself as the cause ; or, in other words, he will regard himself with pleasure. If, on the contrary, he has done anything which, according to his conception, will fill his like with displeasure, he will regard himself with unpleasant feelings. For pleasure and displeasure experienced by beings similar to ourselves, cause the same emotions in our own minds,—*self-satisfaction, vanity, pride, shame, repentance*.

Whenever we conceive that another person loves, desires, or hates something which we ourselves love, desire, or hate, our feeling of love, desire, or hate, will be strengthened. But if we conceive that he dislikes what we love, then we shall experience a vacillation in the emotions of the mind. For the pleasure of another causes us pleasure, and the pain of another has a similar result for us.

Hence it follows, that every one strives to the extent of his power to make others love what he loves, and hate what he hates,—*ambition, proselytism, the desire of exciting suspicion*.

When we have the idea that any one enjoys a thing which one person only can possess, we shall endeavour to deprive him of the possession of it. For the idea that our like enjoys a thing causes us to love and desire it ; but we conceive the possession of the other person to be an impediment to our pleasure,—*envy*.

When we love something like ourselves, we endeavour as far as is possible to make it love us in return. We desire that the being like ourselves which excites pleasure in us should also have pleasure excited in it. This pleasure involves the idea of self as the cause.

We shall be so much the more proud and vain, and have so much the more pleasure in the contemplation of ourselves, the greater the emotion of pleasure which we conceive to be excited by ourselves in the mind of the being whom we love.

The idea that the object of our love unites itself by an equal or stronger bond of friendship to another than to ourselves, will fill our mind with hate towards the object of our love. For the person preferred excites in us painful feelings or envy, and the cause of that feeling is the object of our love. Hence there is a vacillation in our mind between the emotions of love and those of hate and envy,—*jealousy*.

When a person remembers a thing which has formerly given him delight, he wishes to possess that thing under the same circumstances ; but, when he finds that one of the circumstances or conditions is wanting, he experiences painful feelings,—*longing*.

Desire which arises from pain or pleasure, and from hate and love, is so much the stronger, the stronger the emotion is from which it springs.

When any one has commenced to hate a former object of his love, to such a degree that his love is quite destroyed, his hate will be greater than it would have been had he never loved the same object. For the conversion of love into hate requires many more causes than the simple production of hatred.

When a person hates another, he will seek to do him injury, provided he do not fear the production of greater evil to himself from that course; and, on the other hand, one who loves another will endeavour to confer benefits on that other person. For to hate any one is to regard him as the cause of pain to one's self. To put an end to this pain, one's endeavours will be directed to the annihilation of the existence and destruction of the cause.

The idea that we are hated by another person without cause, excites hate in us in return. Hate causes us pain, and the person hating us is viewed with a feeling of displeasure as the cause of that pain.

When any one conceives the idea that the person whom he loves hates him, he will be assailed by the feelings of love and hate simultaneously, as was shown in the foregoing paragraphs.

If a person conceives that another, whom he neither loved nor hated, has done him an injury out of hatred, he will immediately seek to inflict the same injury on that other person.

If a person conceives that he is loved by another person, and believes that he has afforded no cause for that love, he will love in return. For the pleasure excited by us in another excites pleasurable feelings in us. Hence the proneness to yield to false as well as true love, and to flattery.

Again, if a person conceives that he is loved by another whom he hated, he will be assailed by hate and love at the same time.

When a person has, from love or hope of fame, conferred a benefit on another, he will experience pain if he sees that the benefit is received with ingratitude. (Ingratitude itself is the result of a contest between more powerful present feelings and the ideas of former conditions.)

Hate is increased by reciprocal hate, and may be annulled by love.

Hate, which is entirely vanquished by love, is succeeded by love; and this feeling is then stronger than it would have been had hate not preceded it. For the power which conquers the hate is stronger, and is excited more strongly by equal causes.

When any one conceives that another person similar to himself hates a thing also similar to himself, and which he loves, he will hate that person. For the person hating the loved object desires it, and thus excites painful feelings.

When a person belonging to another station in society, or a different people, fills us with pleasure or displeasure, and when with those feelings are united the idea of the person, and that of the station and people as the causes of that pain or pleasure, we shall love or hate, not only the person who excited those feelings, but all persons of the same station or people.

The pleasure which arises from our regarding the hated thing as annulled or filled with another evil, is not unaccompanied by some feeling of pain, inasmuch as we regard a thing similar to ourselves as destroyed.

Love or hatred towards a person is annulled when the pleasure or pain which it excites receives another cause; and it undergoes a change when the cause is distributed amongst several persons.

Love or hatred towards an object which we conceive to enjoy freedom of action, must, when excited by a similar cause, be stronger than when felt towards an object which obeys the laws of necessity. For, in the latter case, the cause is not confined to one, but extends to a chain of events.

Anything may accidentally be the cause of hope or of fear, as anything may accidentally be the cause of pleasure, or of pain,—*good or evil forebodings, superstition.*

Different persons may be differently excited by one and the same object; and even the same person may be excited differently at different times by the same object.

An object which we have previously seen at the same time with others, and which we conceive to have no quality which is not common to several other things, excites us less than an object which we believe to have special properties. The interest felt in the latter case, when accompanied by a feeling of pleasure, constitutes *admiration, veneration, and homage*: when accompanied by a feeling of pain, it is *alarm* or *horror*.

When the mind contemplates itself and its power of action, it experiences pleasure, and this pleasure is greater in proportion to the distinctness of that conception.

The mind strives to conceive only such ideas as set its own power in action. It experiences pain when its own inability or want of power is the subject of its conception. This pain is fostered by the idea of *faults* or *blame*.

Men envy the virtue only of their equals.

Pleasure, pain, and desire, and every mental emotion compounded of these, as well as the wavering of the mind between two feelings, or the emotions due to this state, are manifested in as many different forms of love, hate, hope, fear, &c. as there are varieties of objects which excite them.

Each mental emotion in one individual differs from the same emotion in another, only so far as the natures of these individuals differ from each other. In like manner the passions of animals differ from the human passions, only so far as the nature of animals is different from that of man.

Besides the pleasure and desires which are passive, there are others which belong only to our active state. Such is the pleasure which the mind experiences in the contemplation of its clear ideas, and in the conception of its own state of action.

All those emotions which have reference only to the active state of the mind, are modifications either of pleasure or of desire. *Courage* and *gallantry* are, according to Spinoza, emotions of this kind.

Such is Spinoza's account of the feelings.

Of the varieties of Disposition. (Gemüthsart.)

The *disposition* is the character of the mind as respects the ideas and emotions which refer to self, and to beings allied to self; the suppressed and manifested excitements, and their reciprocal (statical) consequences; and, lastly, the contest between these actions of the mind and the reason.

A person whose mind is but little susceptible of the states of pleasure, pain, and desire, and whose body does not readily undergo the organic changes ordinarily produced by affections of the feeling of self, is said to have an unfeeling disposition, to be cold and indifferent. One who possesses the opposite qualities has a feeling disposition or nature, and his feelings are said to be fine or uncultivated, according as reason does or does not modify and soften the play of the affections.

In a more limited sense, a person is said to have an unfeeling disposition, who, though susceptible of strong pleasurable and painful feelings and desire, from ideas relating to his own individual self, is, nevertheless, little affected by the pleasure or pain of his fellow-men; and who consequently has not made the self of his fellow-men a part

of his own self; extending, as it were, the bounds of his own existence. While whoever has done this is acknowledged to possess, in this more limited sense, a feeling disposition.

The essential foundation of a feeling nature or disposition, in both the first and second senses in which the term is used, is not the power of conceiving complex ideas and relations of ideas. For the excitability of the disposition is connected on the one hand with a particular class of ideas, which relate to self or the individual, or to like beings; and, on the other hand, with the capability of experiencing emotions or strivings of the mind, and changes in these emotions under the influence of ideas of the kind just mentioned. Hence men of small intellect may have much "feeling," and men of great intellectual faculties be "unfeeling." With respect to the feeling disposition in the second sense, namely, the disposition which feels for others,—persons devoid of it will, if endowed with strong intellectual faculties, employ these faculties principally for their own interest; while those who possess such a disposition, whether their intellect be strong or weak, will be interested in the well-being of their fellow-men; not merely after reflection, but immediately, from sympathy, and will feel pleasure or pain in their happiness or suffering.

For this kind of disposition it is necessary, whatever should be the extent of the reasoning faculties, that the idea of self, and of that which is useful to it, be balanced by the idea of that which is useful to all men alike, or that the idea of self should embrace that idea also. A man whose mind has attained this state, to which education contributes much, acts justly, and for the common good after reflection, or he acts in the same way from benevolence, experiencing himself pleasure or pain; in which case his conduct is due to "feeling." In children, the striving for the preservation and advantage of self is at first the principal feeling; for the idea of self is first developed, and connects itself with certain disturbances of the organism, with its sensations and actions. At a later period, and as the result of education, the feeling of self includes the whole family, and their common interest, and thence extends still further, to limits which vary in different cases.

Men who have the same degree of excitability have also different dispositions, according as they are prepared by organization, more particularly for the emotions of pleasure, for those of pain, or for desire, and according as the one or the other kind of ideas meets with a stronger organic disposition to action, or to the depression of the active state.

Animals also are of very different dispositions: they are joyous, melancholy, compassionate, envious, spiteful, affectionate, and jealous. All are capable of manifesting the different emotions or passions; but the susceptibility of changes in their organic system from different ideas varies very much in degree, and the instinctive ideas, which arise

like dreams in their mind, are provisions for the more ready excitement and recurrence of certain trains of feelings.

In man the moral feeling modifies the play of the passions, and, to a certain extent, causes it to depart from the laws laid down by Spinoza.

As long as we are under the influence of passion on account of ourselves or of certain other persons the term "good" expresses merely a relative idea; that, namely, appears good, which favours the existing states of pleasure or desire, while everything is "bad" which opposes those feelings, and excites the feeling of pain and the desires consequent on it. One and the same thing may be good to-day and bad to-morrow. In respect of what is good for all men, that which appears good to us during a particular state of passion may be either good or bad. For envy and pity may spring from the same sources, as the laws already laid down respecting the statics of the passions show. A man who is at one moment full of pity or sympathy, may at the next be envious, without having greater reason for being the one or the other.* Animals are capable of feeling pity or sympathy for each other, and even to a certain extent for man. When he confers good on them, and excites the feeling of pleasure in them, they come to him with pleasure and participate his suffering. In this there is no trace of moral feeling.

The sacrifice of the good of all, or of many, to the good of self, is in some measure restricted, in consequence of the affections of men and animals for their own immediate interest being counterbalanced by other passions, which have also reference to their self; namely, by the fear of punishment,—and in many by the emotions produced by superstition. Superstition, however, is nearly as prolific a source of evil, as of good deeds.

When the prevailing idea in our mind respects that which is generally useful or good for our family, for our class, for the corporation or body of men to which we belong, or for our fellow-countrymen, we conceive a more general notion of "utility" or "goodness." The idea of that which is good for a limited number of persons, and for their different conditions, is, however, still far removed from the notion of what is morally good. The greater the number of persons to whom a good thing conveys a benefit, the more nearly does the idea of it approach the moral good, which implies the notion of what is useful and good to all men. This notion becomes still more perfect, when the thing regarded as good is good for all men, not merely at the present time, but under all circumstances and in all times. Such is also the good which is desirable for the individual self under all circumstances; a notion from which is excluded everything which is good merely in the present condition, but not in those which may follow.

* Spinoza, *Ethik.* 4 Buch.

The submission of self to the divine laws ruling the universe is reason, which recognises individual things as parts of the general whole. Reason produces the notion of the highest good, which is opposed to and restrains the idea of the relative good suited only to the temporary conditions of man; and this is conscience. The contemplation of the imperfection of our own self, which frequently is not guided by the notion of the general good, together with the striving to attain this good, and the feeling of dependence and fallibility, constitute the religious feeling, the prevalent emotion of the pious. The contentment and pleasure, which accord with reason, form the happiness of wise men, who neither despise all other pleasures nor fail to avoid painful ideas, as far as they can do so without acting contrary to the dictates of reason.*

We shall here conclude our account of the passions, with the remark, that they are capable of association, mutual neutralisation, and concatenation; just as are the simple ideas. Many so-called passions are really a connected series of different states of emotion; such is the passion of jealousy. This will be readily intelligible when the foregoing exposition of the passions is compared with the account previously given of the more simple relations of conceived ideas.†

SECTION III.

Of the mutual reaction of the Mind and Organism.

CHAPTER I.

OF THE MUTUAL REACTION OF THE MIND AND ORGANISM GENERALLY CONSIDERED.

THE different views which may be entertained respecting the connection between the mind and the body, have been discussed in the first chapter of the first section of the present book. We have here to consider their modes of reaction on each other. But before entering upon the particular details of this subject, we shall premise some remarks

* See Spinoza, *Ethik*. 5 Buch. Fichte, *Anleitung zum seligen Leben*. Berlin, 1806.

† For further guidance in the wide field of psychological enquiry, I must refer the reader to the different systematic treatises on the mind, and to those works which treat of logic in connection with psychology and metaphysics. Aristotle, *De Anima*. Spinoza, *Ethica*. Herbart, *Lehrbuch zur Psychologie*; Königsberg, 2te Auflage, 1834. Stiedenroth, *Psychologie*; Berlin, 1824. Beneke, *Lehrbuch der Psychologie*; Berlin, 1833. Schubert, *Geschichte der Seele*; Stuttgart, 1839. Bobrik, *System der Logik*; Zürich, 1838. Carus, *Vorlesungen über Psychologie*; Leipzig, 1831. Flemming, *Beiträge zur Philosophie der Seele*; Berlin, 1839.

upon the organic elements of the whole body, as well as of the brain, and upon the monads of metaphysical philosophers.

a. Of the elementary particles of organic bodies, monads of physiologists.

The elementary parts of the brain are, like all the other elementary particles of the animal body, developed from cells; and all these cells are produced from the primary cell or germ, which has the organic properties of the whole. The secondary cells from which the different tissues of the body are produced by various processes of transformation,* differ from the primary cell in respect of their productive power. The primary cell produces all the secondary cells, while the latter are able only to reproduce their like. The cells of cartilage generate only new cartilage cells; the cells of horny tissues, only cells of similar nature; and muscular fibres, only muscular fibres. Hence, we must perceive, that an entire organism, in the form of the primary cell or germ, cannot be reproduced except by the co-operation of all the different secondary cells, or by the dynamic property of the whole, maintaining its integrity and exerting its ruling power over all the different tissues. The fully developed organism, however, consists of a system of parts, all essential to constitute the whole, which are, in a measure, independent of each other, and have the power of generating their like. These particles or cells may be termed secondary monads, inasmuch as they have their origin in the primary monad of the germ, and represent, together, that primary monad in the developed or unfolded condition. The different (secondary) monads composing the organism have, by virtue of their structure and composition, different endowments, viz. those of motion, sensation, nutrition, secretion, &c.; or we may say, that different forces of nature are rendered manifest in them by virtue of their structure. The brain becomes the organ of the mind in consequence of the structure it receives, and of the reciprocal action of its elementary parts, which are cells (the grey corpuscles of the ganglia and cerebral substance), and fibres, developed from cells; just as the cells of muscular fibre and the muscular fibrils become the organs of motion. Nevertheless, it must not be imagined, that the mind, on this account, is itself compound. The increase in number of the elementary particles of the brain has not any influence on the number or mass of the ideas, but only on their lucidity, distinctness, and facility of association. And in accordance with this, we find, that the loss of portions of the cerebral substance, in injuries of the head, does not deprive the mind of certain masses of ideas, but diminishes the brightness and clearness of the conceptions generally. Different ideas, however, are communicated simultaneously to the sensorium, from the different regions of the brain, to which impressions on nerves of sense are conducted.

* See Book VIII. Section II. Chapter II.

The structure of the brain and body generally, being that which we have described—the active particles of both being identical in nature, and alike produced from cells; it is easy to understand how the monad-like particles of the brain should communicate the state excited in them by ideas, to the similar particles of the body, and *vice versâ*. But the mode of action and reaction of the elementary particles of the brain, in the production of ideas, remains a perfect mystery.

It should here be clearly understood, that by monads I do not mean atoms, but those organised perishable elementary parts, of which Schwann has shown all the tissues to be originally composed; parts, which, though subordinate to the plastic power of the whole organism, have yet different compositions and endowments, and are so far independent, as not only to reproduce their like while within the organism, but even to continue their organic action for a certain time after their separation from it, and which frequently coalesce, several together, to form compound structures of similar endowments, such as the muscular and nervous fibres. Mayer had* expressed the notion that organisms were formed of active primary particles or organic monads, long before it could be anticipated that all the tissues would be actually shown to have originally the same structure. I had also an indistinct conception of a similar idea, when, in the first part of this work, in 1833, I endeavoured to explain the regeneration of divided Polypi and Planariæ, and the formation of double monsters by division of the germ. Purkinje, likewise, had been led by his anatomical researches to conceive the existence of independent elementary particles, endowed with special properties and serving the purposes of the organism. Schwann's recent work† furnishes the material for a general theory of organic beings.

b. Monads of the Metaphysicians.

The sense in which we have used the term, organic monads, in the preceding page, is very different from that in which Herbart employs the word "monads" in his treatise on mind and matter. According to Herbart,‡ the mind is a simple substance (Wesen), without parts, without extension, and without any complexity in itself (Vielheit); matter, itself, consists of simple active substances or monads (atoms), destitute of extension, which exist in space, without forming a *continuum*, but which are in a state of equilibrium of reciprocal attraction and repulsion, and thereby acquire the appearance of a body possessed of extension. Matter is impenetrable only with respect to those substances which are not able to produce a change in its existing equilibrium of attraction and repulsion. Every organic body is a system of monads, which are themselves

* In his *Supplemente zur Lehre vom Kreislaufe*.

† *Mikroskopische Untersuchungen*. Berlin, 1838. 8.

‡ *Lehrbuch zur Psychologie*, p. 122—133.

the subjects of a system of internal states, arising from the reciprocal action and reaction of the monads on each other. The combination determined by providence, is the cause of the particular form of an organic body. In the germ, the whole system of internal states subsists in a concentrated condition, without the corresponding form. The mutual reaction of the mind and body on each other, accordingly, consists of the action of the mental monad upon the internal states of the monads of the body, and *vice versâ*. The monad which conceives the ideas, and which, like all Herbart's monads, can be regarded only as a mathematical point, requires no fixed seat in the brain, but may move through a certain space, without the least suspicion of such motion being conceived in its ideas, and without the least trace of it, capable of detection by anatomical research, being left behind. Such change of seat of the mental monad, may be regarded as a very fruitful hypothesis for the explanation of abnormal states of the mind. Herbart further remarks, that there is no reason for supposing the seat of the mind to be the same in all animals and in man. Its seat, he says, may probably lie in the spinal cord in brute animals, particularly in the lower classes. It cannot also be regarded as certain, that each animal has only one mind. The contrary, indeed, appears to be the case in worms, of which, when divided, the separated parts continue to live as independent beings; and in the nervous system of man there may be very many elements, which, in their internal constitution, are far superior to the mind of the lower animals. In separated parts of organic bodies, moreover, life is maintained for a period without the presence of mind. Bobrik* also adopts this view, and deduces from it the explanation of different organic processes. In order that unity, totality, and adaptation to the proposed end should attend the mobility of the vital forces, it is indispensable, says Bobrik, that there should be a ruling monad, able to combine into one system the aggregate of monads already prepared for organic mobility. This ruling monad is the "form." Among the different elementary parts which are gradually developing themselves, some attain such a perfection of their internal conditions, as to become the "forms" of new organisms, or seeds fit for propagation. If this view were applied to the active corpuscles or organised elementary parts of organic bodies, each of those particles, in an organic body, would be a subordinate system of active atoms of only temporary duration, whilst the active atoms or monads of Herbart composing it would be insusceptible of destruction.

c. Of the action of the mind in the organised structures of the brain.

Herbart's hypothesis respecting the monads and the nature of matter, certainly explains the action of the mind upon matter, without the mind

* System der Logik. Zürich, 1838.

itself being supposed to be material ; since, according to his view, the mental phenomena are the result of the action of one simple immaterial substance upon other simple immaterial substances or monads.

On attempting, however, to account for the conception by the mental monad of ideas of objects extended in space, in consequence of changes produced in other parts of the organism, and again, for the action of the mental monad upon numerous fibres of the organism simultaneously, we meet with inexplicable difficulties. The problem requiring solution has always been to explain how the mind, a simple substance, not composed of parts, can acquire from the affection of parts of the body having a certain relative position, the perception of objects having extension in space and particular forms. How, for example, it can obtain the perception of visible objects, occupying a certain extent in space and having a certain form, from the affection of certain points of the retina ; each point of the retina being perceived as occupying a given portion in the field of vision. All perceptions by the sense of vision of objects, having extension in space, are dependent on the different points of the retina being perceived in the same relations of contiguity as those in which they really exist. We may represent such points of the retina by letters, thus :—

<i>a.</i>	<i>b.</i>	<i>c.</i>	<i>d.</i>
<i>e.</i>	<i>f.</i>	<i>g.</i>	<i>h.</i>
<i>i.</i>	<i>k.</i>	<i>l.</i>	<i>m.</i>

We meet with the same difficulty in the case of the sense of touch. For we certainly owe our power of distinguishing by touch, the forms and other qualities of extension in external bodies, to our perception of the relative position of the different parts of our own body. The whole apparatus of vision is so contrived, as to convey an exact representation of the relative position, even of distant objects, to the extended surface of the retina. But if the mind is a substance, to be conceived only as a mathematical point, how can the idea of position be obtained from the simultaneous affection of certain points of the retina ? It might, indeed, be imagined, that such a monad would receive impulses, as it were, from all sides, and that the idea of visual space would arise from the impulses thus given by other monads to the mental monad. But there is no indication in the brain of any provision for such a concentration of all sensual impressions upon a single point. Adopting Herbart's hypothesis, the most ready way of getting rid of the above-mentioned difficulties, would be to deny that we can perceive the relations of position in the sensations of our body. And this has really been done at different times. Steinbuch,* several years since, maintained that we owed our perceptions of the extension and relative position of objects entirely to the motions accompanying those perceptions. Thus, the retina, he said, does not

* Beiträge zur Physiologie der Sinne. Nürnberg, 1811.

perceive the relation of contiguity or position in the different points of it which are affected in vision, but, that knowledge, concerning the objects of vision, is obtained from the action of the muscles of the eye. An illuminated point of the retina is, by the conscious contraction of one of the muscles of the eye, converted into a line of light. In order that other parts of the retina should be illuminated, different degrees of contraction of those muscles are required. According to this view, the act of vision consists not in the retina being the seat of an image, in which external objects are represented in their relative position, but in a succession of muscular contractions, which are necessary, in order to expose different parts of the retina to the same pencil of light. Each point of the retina is supposed to stand in a special relation to a particular degree of contraction of the muscles of the eye, and, hence the illumination and sensation of particular parts of the retina become, by education, but unconsciously, associated with certain degrees of conscious muscular contraction. On more narrowly analysing this view, however, we find that it takes for granted a perfect impossibility. For, unless the distinct points of the retina are by nature different from each other, in the quality of their sensation, it is impossible that they should be distinguished and recognised as distinct, in repeated impressions on them; and unless they are so distinguished, no particular degree of muscular contraction can become associated with them in the memory. And, in fact, Tourtual, who rejects the theory that we can distinguish in sensations the relative position of different points of our body, still admits, that the impressions which the mind receives from all the different points are different in quality, and supposes that it is only by this difference that they are distinguished from each other. But if we reflect, that a new-born animal gives evidence of the perception of position and form, by means of the sense of sight, in its immediately applying itself to the teats, we shall scarcely doubt the fact that, antecedently to all education, impressions of form and position or extension in space are perceived in the retina. Now, admitting the mind to have the power of distinguishing the relative position of different parts of the body, the possession of such a power by a point-like monad appears inconceivable. Even if we suppose that the monad is able to travel over all parts of the retina, and thus to collect an aggregate impression from the different changes it might undergo in its course, there would still be a difficulty in reconciling this view with the simultaneous existence of the different parts of an image,—with the power which we enjoy of perceiving in a moment all parts of an impression occupying a considerable extent. The more probable view, therefore, is, that the mind is present at the same time in all parts of the brain, without itself being composed of parts, and that it recognises the extension and qualities of form and position in the impressions on the senses, by virtue of its general presence.

This, however, must not be regarded as an explanation: for it still remains a mystery, how the closely contiguous particles of nervous substance in the organs of sense can be distinguished from each other in the mind. For if we suppose that they are conceived by the mind, as so many contiguous points exerting a repulsive force upon each other, still this is merely a figurative expression, and the conversion of impressions on organised matter into ideas remains as difficult of conception or as inconceivable as the relation of mind to organisation generally.

It is very easy to cut the knot, by saying, that organisation and the mental principle are different names for the same thing; that the apparent difference between matter and mind is the result of the different manner in which we regard them, and does not really exist. But we cannot lose sight of the fact, that the brain is an aggregate of numerous differently organised parts, and in this respect a highly complicated piece of mechanism; while the mind exists in a latent state, in the germ, independently of this mechanism, although incapable without it of manifesting itself or acting upon the body. The manner in which the mind makes use of this highly complicated and delicate piece of mechanism, is certainly inconceivable.

The problems, concerning which I have here been endeavouring to give my readers some clear conceptions, are, it is true, no subjects for physiological research, and their solution, if possible, must be expected from metaphysical philosophers; but, nevertheless, I have thought it the duty of the physiologist to analyse those questions which lie on the borders of his own science, and to compare, critically, the different results of speculative enquiries, with the view of advancing at a future period more nearly to the truth. I here again refer to the exposition of the cosmological systems given at the commencement of this section. They, together with the doctrine of monads just considered, comprehend the circle of the most general possible conceptions on this subject.

CHAPTER II.

PHENOMENA RESULTING FROM THE ACTION OF THE MIND AND BODY ON EACH OTHER.

So soon as the structure of the brain is developed, and the action of the senses commences, ideas or mental actions also arise; and, just as light may be developed in an inorganic body, by a mechanical shock and change in its physical condition, in the same way changes in the action of the mind may be produced by changes impressed on the organisation of the brain or on the matter which enters into its structure. On the other hand the operations of the mind, with which the organisation of the brain keeps, as it were, equal pace, induce changes in the structure

and component matter of that organ, and of all other parts of the body which are under its influence. The ideas and thoughts are not themselves composed of parts, but they are developed in matter which has organisation and parts, and the distinctness of the conceptions is entirely dependent on the condition of this divisible matter.

Hence we may infer that, whatever changes the mind produces in the organism generally, are effected through the medium of the brain—the organ in which alone the mental force, elsewhere latent, is manifest, and from which its influence radiates, as from a centre, to all other parts of the body. Every organ, also, by virtue of its power of acting on the brain itself through the medium of its nerves and of the blood circulating through the whole organism, must have an influence upon the ideas and upon the power of mental conception. This influence may be either exciting or depressing, so that the power of the mind to conceive ideas may be either increased or impeded. The impressions communicated from different organs of the body to the brain can, of course, produce no other distinct ideas than those of sensations, and the peculiar import of these sensations. But since local changes of particular organs may produce the sensations of pleasure or suffering, or of the tendency of the organ to its specific function, and may thereby excite the ideas of the expansion and restriction of self and of desire, which are associated with those sensations, it is evident that the disposition to a state of emotion may be kept up by the state of other organs than the brain.

1. *Influence of states of the body upon the intellect and emotions.*

The excitement of certain organic states of the brain, by the bright scarlet, aerated blood, is a necessary condition for the action of the mind. Hence, the abstraction of blood in large quantity produces syncope and loss of consciousness. Even the quality of the blood, however, exerts an influence on the intellectual operations. The most common instance of an influence exerted on the mental faculties by a cause of this kind, is afforded in the effects of digestion. The digestion of food introduces a quantity of imperfectly assimilated matter into the circulation. Until this new material has undergone the necessary changes, and while certain matters, altogether unfit for nutrition, are mingled with it, it is not adapted to excite those states of the brain which are necessary for the proper manifestation of mind; and as it is conveyed to that organ by the circulating blood, it produces an injurious change in it, and impedes or disturbs the mental functions. Hence, the indisposition to mental labour experienced by some persons after meals. This disturbance of the intellectual operations is still more evident, as the result of the material changes produced by the alterantia nervina (spirituous liquids and narcotics). Some “secreta” and “excreta,” as bile and urea,

are equally unfitted for producing the natural organic states of the brain. The former substance being absorbed into the blood, produces not only indisposition to the exercise of the intellect, and diminution of its power, but also depression of spirits, by disturbing those organic conditions of the brain which influence the emotionary feelings.

A second source of causes disturbing the action of the mind, through the medium of changes produced in the brain, is found in those states of other organs, which act on the brain through the medium of the nerves. Every part of the body, which stands in the relation of active sympathy with the central organs of the nervous system, is capable, when itself in a state of strong excitement, of exciting strongly the brain, and thereby the mind also; or, when in a state of depressed action, of diminishing the activity of their functions: hence, delirium and stupor are effects of those states in some parts of the body. The emotions of the mind are also affected in this way; long continued disturbance, or arrest of the functions of important organs, giving origin to a fretful, dejected state of feelings, which is nothing else than a state of impeded strivings of the mind. Those organs which are engaged in effecting chemical changes in the organic matters of the fluids, such as the internal viscera, act on the mind in two ways, for they depress the power of action of the central organs, not only through the medium of nervous connection, but also by changes impressed on the blood. The effect of the latter mode of action varies in degree, according to the kind of change produced in the blood by the viscera. Hence it is that the abdominal viscera are distinguished above all others, by the influence of their chronic maladies, in giving rise to a long continued depression of the strivings of the mind.*

There are organs of the body, particular states of which excite passions connected with their functions; such are the sexual organs and the stomach. These organs excite sensations of particular kinds, and ideas of things fitted to restore the integrity of self, which is felt to be in an impaired or restricted state. On the other hand the idea of that which would restore the integrity of self, or increase its power, determines currents of nervous energy towards the particular organ. For, as we have already seen, this idea of a state which can be realised by a particular organ, excites a current of nervous influence towards that organ, whether it be a muscle or a gland. In this way is the disposition to the passion of love excited by particular states of the sexual organs or of the spinal cord, the medium of nervous communication between those organs and the brain. If both the sexual organs and the spinal cord have a certain degree of tension, the mind is thrown into such a state, as causes corresponding ideas to arise. The active state of the organs

* See page 816* of the second edition, or page 818 of the first edition, where the seat of the passions is shown not to be in those viscera.

excites the idea, and the idea may produce that condition of the organs ; but, unless the organs are in a state of potency, the ideas to which they are related remain cold, and do not influence the organic conditions and actions. Particular kinds of food, also, have an influence on particular states of passion by their action on the corresponding organs of the body. Lastly, the state of the whole nervous system, and the degree of its excitability, and of the facility with which impressions are propagated through it, exert an influence on the emotions. For those persons, in whom any excitement spreads very rapidly through the nerves, and still more rapidly leaves behind it a state of exhaustion, are more liable than others to all emotions in which the feeling of self undergoes a violent and sudden change and depression, such as fear, anxiety, terror, &c. But they whose nervous system is differently constituted, and is not exhausted or depressed in consequence of previous excitement, experience from sudden excitement only the emotion of courage, and manifest persevering efforts to maintain or extend the power of self. Animals display different tendencies of their organic states and functions, according as they are by nature timid or courageous. In man, these dispositions to particular emotions vary with the organic state of the body : a person, gifted with great coolness and presence of mind, may be so altered, temporarily, by a particular state of his nervous system, as to be startled like a naturally timid person, by any sudden occurrence ; whilst abundant food and a glass of wine will give courage to the faint-hearted.

The operations of the mind are affected in the greatest degree by changes in the organic conditions of the brain itself, such as inflammation, malformation, and pressure. Every state of irritation of the brain causes delirium ; everything which impedes the organic actions in the brain produces syncope, stupor, or complete coma. Hence the most various structural changes in the brain, as tubercles, pus, extravasated blood and water, give rise to nearly the same symptoms. Pressure of blood, still within its vessels, also produces insensibility. And the effects of inanition are, in this respect, exactly the same as those of pressure.

Structural changes in the brain itself are much more prone to disturb the intellectual faculties than to excite or depress the passions. A depressing passion cannot be intense without the concurrence of ideas, in a certain degree of intensity, which shall keep up the passion ; but when the organic actions of the brain are impeded, this intensity of ideas is impossible : hence, even in these cases, the principal effect of structural change of the brain, appears to be impairment of the intellectual faculties. The organic conditions, on which the integrity of the intellectual faculties depends, exist, without doubt, in the brain itself ; but the elements which maintain the emotions or strivings of self, exist in all parts of the organism.

2. *Influence of ideas and emotions of the mind upon the body.*

The influence of ideas upon the body gives rise to a very great variety of phenomena, which border on the marvellous. It may be stated as a general fact, that any state of the body, which is conceived to be approaching, and which is expected with perfect confidence and certainty of its occurrence, will be very prone to ensue, as the mere result of that idea, if it do not lie without the bounds of possibility. The case mentioned by Pictet, in his observations on nitrous oxyde, may be adduced as an illustration of such phenomena. A young lady, Miss B., wished to inspire this intoxicating gas; but in order to test the power of the imagination, common atmospheric air was given to her instead of the nitrous oxyde. She had scarcely taken two or three inspirations of it, when she fell into a state of syncope, which she had never suffered previously; she soon recovered.* The influence of the ideas, when they are combined with a state of emotion, generally extends in all directions, affecting the senses, motions, and secretions. But even simple ideas, unattended with a disturbed state of the passions, produce most marked organic effects in the body. This we shall now proceed to demonstrate.

a. Influence of the mind upon the senses. Phantasms.

Phantasms or hallucinations are perceptions of sensations in the organs of the senses, dependent on internal causes, and not excited by external objects. These phenomena have been repeatedly confounded with mere ideas, and have been regarded as ideas which are not distinguished from realities. But the very belief in their reality is owing to their being seated in the senses, and having all the truthfulness of real sensations; moreover, this belief in their reality is not an essential character of such phenomena. It would be an error of the understanding to believe in the reality of mere ideas. But these phantasms may present themselves with all the distinctness and force of a real sensation, with colour or with sound, and yet not be mistaken for real impressions from without. The false views entertained respecting these phenomena, have arisen from the hallucinations of the insane having been principally the subject of observation; hence I avoid the use of the term hallucination. The name of visions is a more correct expression for the states now under consideration, when they affect the sense of sight. For they are really affections of that sense, and have their seat as truly in its apparatus as any visual perceptions from external impressions. Even the sensations of the sense of sight, excited from without, afford us the opportunity of observing the influence of ideas on the state of the

* The case is given in the German translation of Sir H. Davy's *Researches on Nitrous Oxyde* (Untersuchungen über das oxydirte Stickgas, 2 Bd. Lemgo, 1814. p. 326).

retina; since certain parts of images acquire an extreme distinctness, from being made the subject of more particular conception by the mind, or, in ordinary language, from the attention being particularly directed to them. (See page 1085.)

Without actual sensations, we are accustomed to conceive the presence of outlines, and, consequently, of forms, in the dark field which appears before the closed eyes. This seems to result from a few particles or points of the retina becoming the subject of conceptions. No illuminated and coloured image is perceived in this case. For such a result, it would be necessary that the particular points of the retina should be conceived as being, not in the state of rest, but in that of action, on which the appearance of light and colour depends. This production of colourless figures in the field of vision, by an action of the mind, is, however, sometimes so perfect, that outlines of objects on which the eyes have been long fixed, return with great distinctness. For example, the forms of structures which have been attentively examined with the microscope, suddenly present themselves to our vision, even though many hours have elapsed since they were actually seen. But not merely outlines of objects which have been presented to our sense of vision, are reproduced; new configurations also appear at times, when external impressions are excluded. This happens frequently to children of active imagination, when they are placed in the dark; faces and terrific forms seem to present themselves to them in outline, and devoid of colour and light. All these phenomena appear to result from some kind of reciprocal action, which takes place between the sensorium and the retina.

The subjective images of which we are speaking have sometimes, however, both colour and light; different particles of the retina, of the optic nerve, and of its prolongations to the brain, being conceived as existing in special states of action. This happens rarely in the state of health, but frequently in disease. These are the true phantasms which may occur to the sense of hearing and other senses, as well as to that of vision. The process by which "phantasms" are produced, is the reverse of that to which the vision of actual external objects is due. In the latter case particles of the retina thrown into an active state by external impressions, are conceived in that condition by the sensorium; in the former case, the idea in the sensorium excites the active state of corresponding particles of the retina or optic nerve. The action of the material organ of vision, which has extension in space, upon the mind, so as to produce the idea of an object having extension, form, and relation of parts, and the action of such an idea upon the organ of vision so as to produce a corresponding sensation, are both equally wonderful; and hence, the spectral phenomena or visions are not more extraordinary than the ordinary function of sight. The following are the states of the body in which the above phenomena are observed:—

a. Immediately before sleep, at the time of waking, and when half awake. Who has not observed the vivid images which present themselves to the eye before sleep; the light which sometimes appears to the closed eyes at that time; the forms sometimes brightly illuminated, which suddenly present themselves, and quickly change; or the sudden sound, as if one called loudly in our ears, which, in that state, is heard without any external cause? * A close attention to one's own condition at the time specified, is quite convincing as to the phenomena in question being real sensations, and not merely ideas. Any one who can watch the changes which take place in himself, at the time when sleep is coming on, will sometimes be able to perceive the images distinctly in the eyes. On waking, too, in a dark room, it sometimes happens that images of landscapes and similar objects still float before the eyes. Aristotle,† Spinoza,‡ and still more recently Gruithuisen, have made this observation. I have, myself, also very frequently seen these phantasms, but am now less liable to them than formerly. It has become my custom, when I perceive such images, immediately to open my eyes and direct them upon the wall or surrounding bodies. The images are then still visible, but quickly fade. They are seen whichever way the head is turned, but I have not observed that they moved with the eyes. The answers to the enquiries which I make every year, of the students attending my lectures, as to whether they have experienced anything of the kind, have convinced me, that it is a phenomenon known to comparatively few persons. For among a hundred students, two or three only, and sometimes only one, have observed it. This rarity of the phenomenon, is, however, more apparent than real. I am satisfied that many persons would perceive these spectres, if they learned to observe their sensations at the proper times. There are, however, undoubtedly many individuals to whom they never appear, and in my own case they now sometimes fail to show themselves for several months at a time, although, in my youth, they occurred frequently. Jean Paul recommended the watching of the phantasms which appear to the closed eyes, as a means of inducing sleep.

b. The facts already mentioned prove that the images seen in dreams,—not the mere ideas of things conceived in dreams,—are phenomena of the same kind as the phantasms. For the images which remain before the eyes when we awake, are identical with the objects perceived in

* A detailed account of these phenomena is given in Moritz and Pockel's *Magazin der Erfahrungsseelenkunde*, 5 b. 2. p. 88; by Nasse, in his *Zeitschrift für Anthropologie*, 1825, 3. p. 166; and in J. Müller, *Ueber die Phantastischen Gesichtserscheinungen*. Coblenz, 1826, p. 20.

† In his *Essay on Dreams*, chap. iii.

‡ *Opera Posthuma*, epist. 30.

our dreams.* Even the blind sometimes see in their dreams images of luminous objects.†

The phenomena hitherto described, may occur to any person in the state of health.

c. The diseases in which the occurrence of phantasms is frequent, are fever, nervous irritation of the brain, phrenitis (in which disease they remain for some time during convalescence), narcotism, insanity, and epilepsy.‡ The well-known bookseller of Berlin, Nicolai, when suffering from intermittent fever, saw coloured pictures of landscapes, trees, and rocks, of half the natural size, which appeared to him even before the cold stage set in, and resembled framed paintings. If he kept his eyes closed, they underwent constant changes; some figures disappeared, while new ones showed themselves. As soon as he opened his eyes the whole vanished. Inflammation of the optic nerve is also attended with the perception of luminous phantasms. A very remarkable case was observed by Lincke,§ in which the extirpation of an eye was followed by the appearance of luminous figures before the orbit, as long as the inflammation consequent on the operation endured. In another case,¶ a female, who was stone blind, complained of having luminous images with pale colours before her eyes. These cases prove that the presence of the retina is not a necessary condition for the production of such phenomena; but on the contrary, that the deeper seated parts of the essential organ of vision are alone required. It is an old and frequent observation, that pressure, exerted on the brain, in persons who have been trepanned, causes them to see flashes of light. Esquirol knew an insane person who saw visions, and in whom, after death, he found both optic nerves in a state of atrophy from the eye to the chiasma.||

In cases of insanity, phrenitis, cerebral irritation, and narcotism, the phantasms are seen even when the eyes are open, and combine with the impressions produced on the sense of vision by real objects.

Simple cerebral irritation, in persons who are not insane, may give rise to what is called the seeing of visions. According to the tendencies of the mind, the phantasms seen under these circumstances will be of a religious, consolatory, and benignant character, or fearful forms of living or dead persons, as in the case of the so-called "second sight" of northern nations. The vision may be seen with the eyes open, the

* See Goethe, *Vorrede zur Farbenlehre*; also the excellent remarks of Gruithuisen, in his *Beiträge zur Physiognomie und Eautognosie*, p. 236.

† See J. Müller, *op. cit.*, and Herman in Ammon's *Monats-schrift*, 1838.

‡ For an account of phantasms seen in the state of narcotism, consult Sir H. Davy's *Researches on Nitrous Oxide*. Richerz, in Muratori, *über die Einbildungskraft*, 2 Th. Leipzig, 1785, p. 123.

§ *De fungo medullari oculi*. Lips. 1834.

¶ *Berliner Monats-schrift*, 1800, p. 253.

|| *Dict. de Scienc. Méd. Art. Hallucinations*.

images from internal causes mingling themselves with those of real objects. In this case, it may happen, that the images of external objects are seen through the phantasms as through a veil. In some instances persons see the forms of other individuals; in others, their own forms. According to the degree of mental culture of the subject of these visions, are they regarded as real, or as the result of a disordered state of the sensorium. In the former case, the spectre-seer not only mistakes his own condition, but he is regarded erroneously, both by the superstitious and credulous multitude, and by the more sceptical persons, who think him a madman or visionary. When a person who is not insane sees spectres, and believes them to be real, his intellect must be imperfectly exercised.

We have instances of persons seeing spectres, and recognising their true nature, in the case related by Bonnet and in Nicolai. Bonnet* knew a gentleman gifted with perfect health of body, with candour, good judgment, and memory, in whom, from time to time, when he neither had recently awaked nor was inclined to sleep, figures of birds, carriages, and buildings appeared, independently of all external cause, and moved before his eyes. Sometimes the carpet of his room seemed all at once to change its pattern. The spectral images, here, were as distinct as real objects. This gentleman, however, judged rightly as to the nature of the phenomenon, and corrected any first erroneous impressions.

Nicolai, whose case is so frequently quoted, was accustomed to be bled twice a year, and to have leeches applied two or three times annually for the relief of hæmorrhoids. During the latter part of the year 1790 both these measures had been omitted, and it was early in 1791 that the spectral illusions first appeared to him. After a violent quarrel and agitation of mind, he suddenly perceived at a short distance in front of him, a form like that of a deceased person. Later in the same day there appeared several other walking figures, which continued to appear for some days. Nicolai could in no way regulate the appearance of these phantasms by his will; he could not even determine the appearance of one person rather than another. The figures were for the most part those of strangers. They appeared both by day and night, and presented the different colours of the flesh and dresses, though the colours were paler than in natural objects. After the lapse of four weeks, during all which time Nicolai continued to walk abroad, the phantasms began to talk. At the end of about two months leeches were applied to the anus, and on the very same day the phantasms began to fade and to move more slowly. At length they seemed to dissolve away, leaving fragments visible for a considerable time. † It is

* Analytische Versuche über die Seelenkräfte. Bremen, 1780. 2 Th. p. 59.

† Berliner Monats-schrift, 1799. Mai. It is known only to a few persons, that

very rarely that the power is possessed of producing at will, in the form of phantasms, while the eyes are closed, images of the objects conceived as ideas in our minds. The cases of Cardanus, Goethe, and a few others mentioned in my essay already referred to, are instances of this power. Goethe, in his tract "*Zur Morphologie und Wissenschaft*," says, "when I closed my eyes and depressed my head, I could cause the image of a flower to appear in the middle of the field of vision; this flower did not for a moment retain its first form, but unfolded itself, and developed from its interior new flowers, formed of coloured or sometimes green leaves. These were not natural flowers, but of fantastic forms, although symmetrical as the rosettes of sculptors. I was unable to fix any one form, but the development of new flowers continued as long as I desired it, without any variation in the rapidity of the changes. The same thing occurred when I figured to myself a variegated disk. The coloured figures upon it underwent constant changes, which extended progressively, from the centre towards the periphery, exactly like the changes in the modern kaleidoscope."

In the year 1828, I had the opportunity of conversing with Goethe upon this subject, in which we were both much interested. He knew that I frequently saw different figures in the field of vision, when I lay quietly down to sleep, with my eyes closed, but before sleep had actually come on; and he was very desirous of learning what forms these images took in my case. I explained to him that I had no voluntary power over either the production of these images or their changes of form, and that they never presented the slightest tendency to a symmetrical and vegetative development. Goethe, on the contrary, was able to give the type for the phantasm, and then the different variations ensued in it, as it seemed, independently of the will, though with regularity and symmetry. This difference accorded well with the characters of our minds, of which the one had all the creative power of the poet, while the other was engaged in the investigation of the actual phenomena of nature.*

b. Influence of ideas upon motions.

Ideas produce motions even more readily than they produce sensations. The following are the conditions in which such phenomena occur:—

1. The resolve to execute a particular motion sets in action the corresponding cerebral nervous fibres, and the motion is effected, if it be possible, through the medium of the cerebro-spinal system of nerves. (See the account of the voluntary movements at page 934.)

Goethe, who had been offended with Nicolai, satisfied his revenge by caricaturing him as the Proctophantasmist, in the scene on the Blocksberg, in *Faust*.

* Compare Abercrombie's *Inquiries concerning the Intellectual Powers*, Edinb. 1830. On the phantasms of the sense of hearing, see my own work already referred to, p. 80, and Froriep's *Notiz*. B. x. p. 10.

2. The idea of a particular motion also determines a current of nervous action towards the necessary muscles, and gives rise to the motion, independently of the will. In this way the movements of yawning, laughing, &c., are produced involuntarily, when another person is seen to yawn or laugh. (See page 932.)

3. Any sudden change in the ideas, though without emotion, and having reference to mere external objects, may excite involuntary motions; such as that of laughter. We have instances of a similar kind in the motions which occur when two ideas are suddenly conceived to contradict each other, or when the solution of a difficulty is conceived unexpectedly.

4. The idea of our own strength gives strength to our movements. A person who is confident of effecting anything by muscular efforts, will do it more easily than one not so confident in his own power. The idea that a change is certainly about to take place in the actions of the nervous system, may produce such a change in the nervous energy, that exertions hitherto impossible become possible. This is still more likely to be the case, if the individual is at the time in a state of mental emotion.

5. The passions or emotions themselves give rise to involuntary actions or relaxations of muscles, according as the state of passion is dependent on exciting or depressing ideas. The same passions occurring frequently induce a fixed expression of the features, and betray the characteristic temper of the mind, in the same way that each passion which occurs declares itself by its corresponding physiognomical motions. (See pages 932—934.)

c. Influence of ideas upon nutrition, growth, and secretion.

The phenomena arising from the influence of ideas of the mind upon the organic processes of the body are very analogous to the foregoing. They may be arranged as follows:—

1. Excessive exercise of the mind diminishes the activity of the nutritive processes.

2. An idea having reference to a secretion causes a stream of nervous energy to be directed towards the secreting organ; and, if the mind is at the same time occupied by a passion or an emotion, the effect just mentioned is more marked. Thus, the saliva is secreted in greater abundance when the idea of food occurs to the mind; the secretion of milk is increased when the young are about the mother, and when the idea of them, rendered intense by emotion, occupies her mind; the conception of voluptuous ideas causes the semen to be secreted in larger quantity.

3. The idea that a structural defect will certainly be removed by a certain act, increases the organic action of the part, and sometimes pro-

duces a cure. Hence, the cure of warts by what is called sympathy; *si fabula vera*.

4. The passions sometimes excite profuse secretions, such as a flow of tears, or perspiration, or diarrhœa; sometimes they repress the organic chemical processes by which the secretions are formed, so as to alter their quality. From the latter cause, the milk of a woman who is nursing becomes after a fit of passion indigestible and irritating to the child. Under certain circumstances, also, the passions cause the suppression or retention of secretions: thus the urine is watery, from the natural ingredients of that fluid not being eliminated, after a fright; and anger, grief, and other emotions give rise to jaundice, by causing the matter secreted to be re-absorbed into the capillary blood-vessels of the liver, instead of being carried out by the branches of the bile-duct.

5. Predispositions to particular diseases of nutrition speedily manifest themselves by actual lesions under the influence of passions. Grief, and deep suffering, in a very short time develop phthisis, liver disease, and affections of the heart, when a predisposition to those maladies previously exists.

6. The culture of the mind by observation and varied attainments has an ennobling influence on the corporeal form, and particularly on the lineaments of the face. A comparison of the forms and features most general in the different classes of society leaves no doubt as to the truth of this remark. The form which is acquired becomes hereditary. This influence is most manifest in the most exclusive ranks of society, which seldom intermarry with other ranks, and in which the education of the children is carefully attended to. The only way in which we can conceive the form of the features to be influenced by the culture of the mind is, that all excess of nutritive matter is removed from them, and their formation more strictly confined to the type of the organism.

Of the mental phenomena in compound and divided animals, and in animals united by abnormal concretion.

a. In compound animals.

Among the lower animals there are many which really represent systems of numerous individuals, united by one common stem. Plants, likewise, are aggregates of many concurrent individuals rather than simple organisms. For the leaf-buds of a plant are individuals which have all the same structure, have the power of independent existence when separated artificially or spontaneously, and are capable of developing new systems of similar individuals. The vessels of each bud are prolonged in the vascular layers of the common stem as far as the root, and thus the stem resembles a fasciculus of distinct individual plants, which develop themselves at different points of its length.

The compound animals comprehend the compound Vorticellinæ, Polypifera, Entozoa, and Mollusca, as well as all those animals which propagate by division, at the period when their separating parts are not wholly detached. The distinct individuals of the compound animals are sometimes united by a common stem, of which they represent the branches, and from which they are developed by the formation of buds ; as in the case of the compound branched polypes. Sometimes they are united in a radiate manner, which is the form of the Botrylli; whilst in other cases many are connected in one mass, or, like the Infusoria, which propagate by longitudinal division, they are united in a lateral series ; or, again, like other Infusoria, and some Annelida,—which propagate by transverse division,—they are connected in a longitudinal chain. Most plants, and all the compound animals, are to be regarded as families of individuals, which either are developed singly upon the common stem, as in the majority of instances, or are compound even in their embryonic condition, as is the case with the Botrylli, according to the observation of Sars.* In some instances the different individuals composing the compound animal have certain important organs in common. Thus, in the Sertulariæ, the canal of the stem communicates with the digestive cavities of each single polype. In the Hydriæ, it was observed by Trembley that the digestive cavity of the young polype at first formed part of that of the parent animal, and that the food passed from the one to the other. In the Nais, also, during the development of several new individuals by division, the intestinal canal is continued through the whole series, and the parent animal takes food for them all. In those Annelida which undergo spontaneous division, the imperfectly formed, new creatures, which are merely composed of a certain number of the segments of the parent animal, at one period evidently obey the sensorium seated in the cephalic portion of the parent, and execute its desires and resolves. But, in proportion as their separation becomes more complete, and the parts which are to form the new animals become independent, and acquire new centres of nervous action by development of their cephalic portion, each of these new worms, also, becomes endowed with special will and desires, which it manifests distinctly enough even before it is quite separated, by its attempts to detach itself from the body of the parent worm.

The distinct polypes, which are united by a common stem in the compound Polypifera, are independent individuals, endowed with an independent will and nervous centre. The irritation of a single polype causes the retraction of that one only, and not of all the polypes of the stem. The stem itself has no individuality ; it has no will, and is incapable of conceiving any objects of desire. In it, however, resides the power of producing new individuals by the process of germination.

* Forriep's Notizen, 1837, No. 51.

In the persistent branched polypiferous animals, the stem is not even capable of motion by the will of the individual polypes. Rapp, it is true, observed occasionally slight motions of a peculiar character in the stem of *Veretillum*, but these did not resemble voluntary motions. The *Hydræ*, while they are undergoing multiplication by germination, are compound systems of individuals, but these individuals after a time separate from each other; and the stem in them does not bear the same relation to the separate polypes as it does in the permanently compound *Polypifera*. The stem of the *Hydra* constitutes from the first the main part of the parent polype, and is subject to the cephalic portion of that individual; while, on the other hand, the young polypes manifest the influence of their will only as far as the point at which they are connected with the parent trunk, and at which their separation from it afterwards takes place.

b. Double monsters of the human species and of brutes.

Respecting the mode of formation of these double monsters, all that is essential has already been said. The following natural divisions include their various forms. The abundant examples contained in the Museum of Berlin may all be referred to one or other of the following general heads:—

I. The axis of the body in part double.

a. The upper part of the trunk double, while the lower part is single. *Axis sursum duplex.* Of this form of double monster, in which the cephalic and spinal axes are bifid at the upper part, there are all degrees, from the monster with a double muzzle or double head, to that in which the whole upper part of the body, as low as the sacrum, or still lower, is double.

b. The lower part only of the trunk or axis of the body double. *Axis deorsum duplex.* Of this form, also, there is every degree, even to that condition in which the entire trunk, and even the posterior part of the head, are double, and only the snout single.

II. *Axis duplex.* Two bodies with their axes distinct, united by identical parts with or without defect at the point of union.

a. Union without deficiency of parts; all parts of the two embryos being perfect. In this case each embryo seems to be partially cleft.

For example, in the head of one, $a\frac{b}{b}$, the two halves of the face, b and b , are separated from each other, the occiput, a , remaining undivided; and, in the same way, the two halves of the face, β and β , in the head, $\frac{\beta}{\beta}\alpha$ of the other embryo, are separated, while the occiput, α , remains single. Hence there is this confusion, $a\frac{b\beta}{b\beta}\alpha$, of the parts of the united

heads; each face, δ , β , of the double head being composed of halves, which belong to two different embryos. The examination of the cranium and brain proves that this is the case.* The syncephalus, synthorax, and syngaster, as well as the pygodidymus of Gurlt, when not combined with deficiency of parts, are varieties of this form of monstrosity. The syncephalus, without deficiency of parts, is the true Janus-monster. But there are cases of synthorax and syngaster, in which the condition of the thorax and abdomen is the same as that of the head in the Janus-monster.

b. Two embryos united by identical parts, with defect at the place of coalescence. Monstrosities of this kind are due to the same principle as the coalescence of corresponding organs of the two sides of the body in single monsters. The coalescence and loss of parts may be situated either at the side or at the front of the body. Such are the syncephalus aprosupus, in which the faces of both embryos are deficient, and the corresponding forms of the synthorax and syngaster. From the lateral syncephali there is a gradual transition to the monsters with partially double axis.

c. Two bodies united by dissimilar parts.

III. *Implantatio*.—Two bodies united, but only one perfectly developed, while the other remains in a rudimentary state.

a. Implantatio externa.—1. *Implantatio externa æqualis*, in which the parts of the imperfect embryo are connected with corresponding parts of the perfect one; as, for example, where the posterior parts of the body of a diminutive fœtus hang to the front of the thorax of a fully formed child; or where a third foot, parasitic hand, or supernumerary jaw is present. 2. *Implantatio externa inæqualis*, in which the perfect and imperfect fœtus are connected by dissimilar points.

b. Implantatio interna; where one fœtus contains within it a second.

IV. Parts of the body external to the axis, cleft so as to be double. It is sometimes difficult to distinguish this form of monstrosity from the preceding.†

Our knowledge respecting the mental phenomena of double monsters is very limited, the opportunity of observing them occurring very rarely, and most of these monstrous fœtuses dying soon after birth. Some few observations, however, have been instituted upon the most important forms of monstrosities. In that form in which the upper part of the axis is double, and the lower part single, it is found that the two heads do not each possess voluntary influence over the entire lower half of the body, as might have been expected; but that the right head moves only the right half of the body and the right lower

* Compare J. Geoffroy St. Hilaire, *Hist. des Anomalies*, tom. iii. p. 110.

† On the anatomy of the double monsters, consult Barkow, *Monstra animalium duplicia per anatomen indagata*. Lips. 1828.

extremity, while the left head moves the left half of the trunk and left lower extremity. These results have been obtained by observations instituted in the case of Rita Christina.* Irritation of the right foot also was felt only by the right head, and irritation of the left foot only by the left head. It was only when the middle line of the body was touched that it was felt by both heads. This form of monstrosity, therefore, would appear to result rather from the fusion or coalescence of two embryos, with loss or destruction of the intermediate parts, than from the partial division of one germ. In Rita and Christina the intestinal canal was double as low as the ileum, but thence downwards it was single. The desire of evacuating the bowels was almost always felt simultaneously by both. There can, consequently, be no doubt that the single part of the intestinal canal was produced by the coalescence of two intestinal tubes, of both of which a part of the walls was lost. †

With respect to the monsters in which the brain and cranial cavity are single, while the muzzle or the trunk is double, I have myself had the opportunity of making a single observation upon the laws of their sensations and volition. It was in the case of a calf, of which the body and occiput were single, but the anterior part of the head and the muzzle double, there being three eyes, of which the middle one resulted from the fusion of the internal eyes of two faces. It is now many years since I saw this calf alive; I was able to observe it only for a short period, and know nothing of its anatomy. As the creature was not my property, I was interested only in ascertaining how it was affected by sensations. I touched, therefore, one of the mouths with a stick and was surprised to see the tongues of both mouths protruded simultaneously and in exactly the same manner. I cannot exactly recollect whether both tongues diverged when protruded, or whether they both moved towards the same side; but I am rather inclined to think that the former was the case. It is much to be desired that the opportunities of observing such cases should not be neglected. The simultaneous manifestation of one will in both the double parts of such monsters would accord better with the idea of their being produced by partial division of the germ, than with that of their being due to the coalescence of two germs.

The cases of *implantatio* are most frequently met with. The parts of the imperfectly developed embryo, when destitute of head, are generally void of sensibility, the perfect individual being conscious of no sensation from impressions made upon them. Such was the case in the body examined during life by Burdach,‡ in which four well-formed

* Serres, *Recherches d'Anatomie Transcendante et Pathologique*. Paris, 1832.

† Compare J. Geoff. St. Hilaire, iii. p. 189.

‡ Med. Zeitung des Vereins für Heilkunde in Preussen, ii. 209.

extremities hung from the superior abdominal region. This monster is preserved in the Anatomical Museum of Berlin. The appended extremities receive no nerves from the larger trunk, but are nourished by its mammary arteries.* Cases of this kind, however, have been observed, in which irritation of the rudimentary remains of the second embryo was felt by the fully developed individual.† And this appears in no way impossible, when we consider that the new noses formed by the rhino-plastic operation are at first insensible, but gradually acquire feeling. Hitherto, it has never been observed, that both heads of a double-headed monster have exerted voluntary influence over the entire single trunk. The possibility of this occurring, however, at least in the lower animals, cannot be absolutely denied. It is, indeed, much to be desired, that some accurate observations should be instituted upon the double-headed *Hydræ* with single trunk, which, as Trembley has shown, may with great ease be artificially produced, by dividing longitudinally the cephalic end of a polype. In the branched *Vorticella*, *Carchesium polypinum* of Ehrenberg, which propagates by spontaneous longitudinal division, the separate individuals thus produced are seated upon one stem endowed with muscular contractility. In this animal, therefore, the subjection of one common trunk or stem to two centres of volition may, perhaps, exist.

c. Influence of the mind of the mother upon the fœtus.

The connection subsisting between the mother and the fœtus resembles that between the parent polype and the gemmæ or buds developed upon it, which have each an individual vitality, and gradually acquire an isolated condition and independent centres of action. In the latter case the will of the parent trunk has no influence over the motions of the developed germ, and we have no more reason to expect such an influence in the case of the human subject and mammalia. In the *Nais*, which multiplies itself by spontaneous division, the part which subsequently becomes a new individual moves under the directing influence of the brain of the original worm; but this is a different case: it is not the development of a new organism from an unorganised germ, but the mere isolation of a part from another organism, to the will of which it has been subject.

The influence of the mind of the mother upon the nutritive processes of the fœtus must also be considered in this place.

The general question which should first be determined is whether the influence of the mind is so extended that determinate ideas of physical and tangible phenomena are able to cause their own realisation by corresponding plastic changes in any part of the organism.

* For a description of several similar cases, see J. Geoff. St. Hilaire. Op. cit.

† Ibid. p. 227. 231.

That the mind has such an influence over the sensations and motions is beyond a doubt. But the question is, whether the idea of a special form with a particular colour can cause the organism to realise this form and colour by a change in a part of the skin of the body. This question is involved in that respecting the influence of the imagination of the mother upon the organisation of the fœtus; but in the latter case we are required to admit that the mind can exert an influence even external to the organism to which it belongs.

The cure of small organic lesions, such as warts, through the medium of the imagination, cannot be adduced in support of the affirmative of the above question; for in such cures the mental idea does not produce a definite form, but merely excites an increase of the natural nutritive process. The natural organic action being increased is inimical to the existence of a morbid growth, such as a wart; and, hence, the latter wastes. But the imagination of the mother is supposed to produce some positive results,—a modified structure, even in form corresponding with the efficient idea. That such an influence exists is improbable, from the mere circumstance that it is supposed to extend from one organism to another; for the connection of mother and child is nothing more than the closest possible juxta-position of two organisms in themselves perfectly distinct, which exert an attraction on each other by their contiguous surfaces, and one of which receives its nutriment and warmth from the other. But there are many other reasons which tend to refute this old and popular superstition. Nearly all the monstrosities born in Prussia are brought under my observation; and, nevertheless, I can assert, that a new form scarcely ever presents itself, but, on the contrary, that the great mass are constituted of certain kinds of monstrosities constantly repeated, which belong to the great categories of arrests of development, divided or cleft parts, defects, coalescence of lateral organs with deficiency of the intervening parts, &c. In the accounts given of these monsters, however, it is frequently stated that the mind of the mother when pregnant was strongly affected by some object, and the way in which this happened is described, although the monstrosity presents not the slightest resemblance to the object in question. Moreover, since every woman during her pregnancy must certainly be frightened several times, and since very many have once at least, if not oftener, a presentiment of evil from such frights without any result following, it is clear that, when a monster happens to be born, circumstances will not be wanting to afford an explanation of its occurrence conformably with the popular belief.

The only way, therefore, in which the mind of the mother can reasonably be supposed to affect the fœtus, is by a sudden emotion in the former producing an equally sudden change in the organic actions subsisting between her and the fœtus, so as to bring about an arrest of development

in the latter, or to fix its forms at certain transitory stages of metamorphosis; without the idea in the mother's mind having any direct influence upon that part of the foetus in which these arrests occur. Most monsters are abnormally formed in several distinct parts, and frequently we find arrests of development in very different and distant parts of the same foetus.

If we are correct in denying that ideas conceived in the mind of one organized being, can be realised in the structure of another individual; then it will be scarcely probable that one person can influence the ideas of another in any other way than by speech or signs. Even though it should be admitted, that organic beings may exert unknown or what are called "magnetic" influences on each other, and, perhaps, without contact, through the medium of the nerves; still the communication of ideas or particular states of the mind from one person to another, as in the pretended phenomena of animal magnetism, &c., would remain as improbable as it is inconceivable.

CHAPTER III.

OF THE TEMPERAMENTS.

THE temperaments are peculiar, permanent conditions or modes of mutual reaction of the mind and organism. They are chiefly dependent on the relation which subsists between the "strivings" or emotions of the mind, and the excitable structure of the body. Men differ in their capability of conceiving merely simple or general ideas; in their faculty of abstraction, reasoning, memory, imagination, and power of combining ideas: such differences, however, do not constitute the temperaments, but rather the varieties of talents. The temperaments at present recognised, have been distinguished from the earliest times, and no better division of them could perhaps be proposed. The views on which the older writers based their division of these temperaments, were, however, as incorrect as their notions respecting the primary elements of the human body. Galen's distinction of the sanguine, phlegmatic, choleric, and melancholic temperaments was founded on the hypothesis of the Greek philosophers, concerning the four elements of nature,—air, water, fire, and earth, and the corresponding qualities of heat, cold, dryness, and moisture. It was supposed that there were four corresponding primary components of the human body, namely, blood, phlegm, bile, and black bile; and the preponderance of one or other of these components in different persons was imagined to produce the different temperaments.

It would very little aid the elucidation of this subject to relate all the various divisions of the temperaments that have been proposed. We

might certainly expect to find the temperaments connected with the great functions of the body, and with the systems of organs subservient to those functions; for example, to find different temperaments produced by the preponderance of the vegetative (nutritive), motor, or sensitive systems. In this case we should have a vegetative, a motor, and a sensitive temperament. But the mental peculiarities of the temperaments are not dependent on the excessive development of these systems of organs. Great muscular power is far from producing a choleric individual; and the phlegmatic temperament occurs both in those whose vegetative or nutritive functions are well, and in those in whom they are ill performed. All well nourished and stout persons are not phlegmatic, and many who are very thin have that temperament in a marked degree. Choleric persons, also, may be well nourished or thin, of a muscular or of a delicate build; and the same may be said of the sanguine. All the attempts to characterise the temperaments by a particular structure of body are defective. We ought, in fact, to distinguish from the temperaments particular physiological constitutions of the body, which are really dependent on the relative development of the different systems of organs, such as the muscular, vegetative, and sensitive constitutions; though these may be combined with peculiar temperaments.

Much confusion has arisen relative to this subject, from a proper distinction not having been drawn between the pathological constitutions of the body and the temperaments of the mind. It has been imagined that persons of the phlegmatic temperament are bloated, pale, and leucophlegmatic; a state which would indicate a relative excess of the liquor sanguinis in comparison with the red particles of the blood. Hence a predisposition to diseases of the fluids, scrofula and chlorosis, was supposed to attend this temperament. The sanguine temperament has been confounded with the phthisical constitution or consumptive habit, and has been regarded as predisposing to fever, pulmonary disease, and active hæmorrhages. Choleric persons, again, are supposed to be liable to hepatic disease. All such notions arise from the error of not distinguishing the leuco-phlegmatic, phthisical, hepatic, and nervous constitutions, and other abnormal predispositions of the body, from the temperaments of the mind. There are many choleric persons, who, when labouring under emotion, suffer in any other organ sooner than the liver; who, for example, become affected with indigestion, palpitation of the heart, or nervous tremors and twitchings. Persons of the morbid bilious constitution of the body will have a yellowish tint of the skin, and will suffer disorder of the liver, not merely when they are affected with grief and anger, but when they are subject to any mental emotion.

According to my view, the temperaments are entirely dependent on the different degrees in which different individuals are disposed to the strivings and emotions arising from the depression or excitement of the feeling of

self; in other words, on the different degrees of disposition to the states of desire, pleasure, and pain, and on the extent to which these states of the mind are promoted by the composition and states of the organs of the body. We have already stated it to be probable, that the strivings or emotions of the mind are due to that fundamental property of organic beings, which causes them to seek the integrity of self, and which, without even exciting distinct sensations, yet influences the conception of ideas and enters into combination with them.

When the organisation of an individual is such, that his mental strivings or emotions are neither intense nor enduring, he is of the *phlegmatic* or unexcitable temperament, in which the ideas of things, and the combinations of these ideas, remain, more or less completely, mere ideas, uncombined with any strong feelings of the restriction or expansion of self,—unmodified by pleasure, pain, or desire. The phlegmatic temperament to which we here allude, is by no means a pathological condition. In persons of this temperament ideas are conceived with as much rapidity as in others, and there may be the same power of mind as in other temperaments. When the intellectual faculties are good, this temperament will render a person capable of more difficult acts, and successful in a more extraordinary degree, than would be possible were his impulses rendered stronger by a more passionate temperament. Such a person, whose mental strivings, or emotions, are not violent, remains cool and undisturbed, and is not drawn away from his determined course to the performance of acts which he would repent on the morrow;—he is more sure and trustworthy than persons of an opposite temperament, and his success is more to be depended on: in times of danger and at moments of importance, when good judgment, calculation, and reflection are needed rather than very quick action, his powers are all at his command. Great energy of action, which is dependent on the susceptibility of the strivings of self, is not to be looked for in a truly phlegmatic subject, such as I have described; but, in place of it, all the good effects of delay and cautious calculating endurance. Circumstances which would excite the choleric and sanguine to hasty passionate acts, and would cause them painful and bitter feelings, are regarded by the phlegmatic without emotion, exciting merely his meditation; so that he neither complains nor takes part in them, but pronounces dispassionate reflections upon mankind and their conditions. He does not feel his misfortunes strongly, bears them with patience, and is also not affected in any great degree by the sufferings of others. He contracts few friendships, but he does not violate those which he has formed, and may be a perfectly trustworthy and useful man in society. Where rapid action is required, the phlegmatic person is less successful, and others leave him behind; but when no haste is necessary, and delay is admissible, he quietly attains his end, while others have committed error upon

error, and have been diverted from their course by their passions. The phlegmatic person knows his proper sphere, and does not trespass on that of others or come into collision with them. From this conduct, as well as from an orderly and steady course of action, in which he keeps his object in view, and avoids self-deception, he derives a contented tone of mind, free alike from turbulent enjoyments and deep suffering.

That kind of phlegmatic disposition which is characterised by sluggishness, apathy, want of sympathy, irresolution, tediousness, difficult comprehension, and slow mental progress, and which prefers pain not acutely felt to labour and exertion, is an abnormal or pathological condition. The more excitable or unrestrained temperaments are the choleric, sanguine, and melancholic. The passions are the manifestations of the emotions or strivings of the mind, and of the restraint or exaltation of these strivings, attended with feelings of pain or pleasure and produced by ideas of particular objects. The striving of the mind may be so strong, and the attendant organic actions so inexhaustible, as to overcome all impediments; or the pleasurable or painful emotion may be intense, while the sensibility is excessive, and the reaction by continued strivings of the mind and organic action relatively feeble. In the first case the temperament is the choleric; in the second, it is either the sanguine or the melancholic, both of which are dependent on the same essential quality of mind, and are more nearly allied to each other than to the other temperaments.

The choleric person exhibits a power of action remarkable both for intensity and endurance, under the influence of passions or desires which have reference to himself or others. His emotions are highly excited whenever he experiences any opposition or check to the strivings of his mind, whenever these strivings tend to the extension of the power of self, or merely to the maintenance of its integrity; and his ambition, his jealousy, his revenge, and his love of rule, know no bounds as long as he is under the influence of passion. He reflects little, but acts unhesitatingly, either because he alone is right, or more especially because it is his will so to act; and he is not readily convinced of his errors, but persists unalterably in the course to which his passion prompts him until he ruins both himself and others.

In the sanguine temperament the main tendency of the mind is to the feeling of pleasure; while there is great excitability but little durability of the states of emotion when excited. An individual of this temperament is much the subject of pleasurable feelings, and seeks that which will excite them; he readily sympathises, and forms many friendships, but as readily relinquishes them; frequently changes his inclinations, and is little to be depended on; he is easily enraged, but as soon relents; promises readily and much, and is sincere at the time, but neglects his promises if they are not immediately performed; con-

ceives many projects, but never executes them; is charitable towards the faults of others, and expects the same indulgence for his own errors; lastly, he is easily appeased, is open-hearted, amiable, good-tempered, social, and uncalculating.

The feeling of pain is the fundamental tendency of the mind in the melancholic temperament. The melancholic person is as easily excited as the sanguine, but in him painful sentiments are of longer duration and more frequent than pleasurable feelings; the sufferings of others excite his deep sympathy; he fears, repents, mistrusts, and has misgivings on every occasion, and pays especial attention to everything which favours this tone of mind. He is prone to fancy himself offended and injured, or neglected; impediments which he meets with render him dejected, timid, and doubting; and he loses the power either of acting or of judging. His desires are full of sadness, and of the feeling of having suffered a loss; his grief is immoderate and inconsolable.

These delineations of the principal features distinguishing the temperaments might easily be extended; but to enter into any further details would be exceeding the bounds of our proper field of inquiry.

CHAPTER IV.

OF SLEEP.

THE excitement of the organic processes in the brain which attends an active state of the mind, gradually renders that organ incapable of maintaining the mental action, and thus induces sleep, which is to the brain what bodily fatigue is to other parts of the nervous system. The cessation or remission of mental activity during sleep, in its turn, however, affords an opportunity for the restoration of integrity to the organic conditions of the cerebrum, by which they regain their excitability. The brain, whose action is essential to the manifestation of mind, obeys, in fact, the general law which prevails over all organic phenomena,—that the phenomena of life being particular states induced in the organic structures, are attended with changes in the constituent matter of those structures. Hence, the longer the action of the mind is continued, the more incapable does the brain become of supporting that action, and the more imperfectly are the mental processes performed, until at length sensations cease to be perceived, notwithstanding the impressions of external stimuli continue. This is entirely analogous to what frequently occurs during the waking state in the case of individual sensations. A coloured spot regarded stedfastly for a long time becomes at length invisible; and nothing more than a

general impression on the retina, without defined details, is perceived. In persons of feeble nervous system long direction of the sight to one object causes the whole field of vision to become dark. Not merely the action of the mind, but the long-continued exertion of other functions of animal life, such as the senses or muscular actions, induces the same exhaustion of the organic states of the brain, and thereby want of sleep and sleep itself; for these different systems of the body participate in the change which the organic condition of any one of them may undergo. Lastly, impairment of the normal organic state of the brain by the circulation through it of blood charged with imperfectly assimilated nutriment, as after full meals in which spirituous drinks have been taken, also induces sleep. The narcotic medicaments act still more strongly by the change they produce in the organic composition of the sensorium. Even the increased pressure of the blood upon the brain, produced by the horizontal posture, may become the cause of sleep. In many persons, for instance in myself, sleep is brought on at will by the assumption of the recumbent position, while the thoughts are kept in an unexcited state.

The duration of the periodical state of sleep, and the time at which it occurs, are dependent partly on external and partly on internal causes. Sleep generally occurs at night-time, while the waking state is coincident with day, on account of the senses, and consequently the brain, being subject to many causes of excitement during the day, but to few or none at night. The causes which determine the duration of sleep and waking are seated, however, in the organism itself. The day may become the time of sleep instead of night; and if a person keeps himself in a state of activity every night, he will sleep as long by day as he would otherwise have slept by night. It is, moreover, the nature of many animals, for example of the so-called nocturnal animals, to be in action during the night, and to rest by day.

The periodical recurrence of sleep and the waking state is, therefore, essentially connected with something in the nature of animals, and is not dependent on the simple alternation of day and night. But the periods of sleeping and waking, in accordance with a pre-established harmony of nature, have been made to agree with those of the earth's revolutions.

In this respect the short periods of twenty-four hours, during which the alternation of sleeping and waking occurs, correspond to the longer periods of alternate rest and activity which animals present in the rut, in their migrations, in the changing of their feathers (moulting) and hair, and in hybernation and the summer-sleep. For, although hybernating animals fall into the torpid state on account of their inability to maintain undiminished their state of vital activity and power of developing heat without the aid of external warmth, yet, even in them, as the experiments of

Czermack and Berthold have shown, there is an internal cause resident in the organism itself, which renders periodic rest necessary for the restoration of their excitability. The rellmouse, *Myoxus glis*, frequently is torpid in the summer; and the dormouse, *Myoxus avelanarius*, hybernates in the winter, whether it is in the open air or kept in a heated chamber; the only difference being that the sleep is more profound in a cold atmosphere, and comes on earlier than in the heated room. In the open air the animals become torpid as early as October; while in the warm room they wake every day for a certain time until about the middle of December, when the sleep becomes more and more continued, and deeper, so that it is not again interrupted, or only very rarely, before the middle of March. The cause of hybernation, therefore, according to Berthold, is not external cold alone, nor the want of food, but a general deficiency of vital energy, analogous to that displayed in the moulting of birds and similar phenomena, and connected with the changes of the seasons.*

The daily sleep of plants, and their winter sleep, present in this respect exactly similar phenomena, and prove that neither the internal tendency to periodical phenomena, nor the dependence on external stimuli, is peculiar to organic beings supplied with nerves and a central source of action.†

The waking of plants is manifested by the expansion of their leaves, and the turning of their upper surface towards the light. The sleep of plants, first noticed by Cordus, and afterwards observed by Linnæus to be a general phenomenon, consists in the leaves assuming the erect position, and folding themselves together. During the day, also, plants inhale carbonic acid, and exhale oxygen, while at night they absorb oxygen from the atmosphere. The movements attending the sleep of plants are most evident in the youngest leaves of the stem, and in the petals of the flowers, and least manifest in the older leaves. The sleep of young animals, also, is most profound. There are plants, as well as animals, which sleep through the day and are awake by night; the stimuli afforded by day being in both cases less adapted than the conditions of night to maintain the activity of the organism. In most plants, as in animals, sleep is the result of the state produced by the continued stimulus of light, and of the absence of this stimulus during the night-time. For, according to the experiments of Decandolle, the period of the sleep of plants may be reversed by producing artificial night and artificial day. But still there is a cause both of the sleep and waking seated more deeply in the organism itself. From the observations of

* See Müller's Archiv. 1835, p. 150; 1837, p. 63.

† See the instructive paper on the sleep of plants, by E. Meyer, in the Vorträge aus dem Gebiete der Naturwissenschaften und der Œconomie, herausgegeben von C. von Baer. Königsberg, 1834, p. 127.

Duhamel, Ritter, and Decandolle, we learn that the leaves of plants kept in constant darkness, open and close at regular intervals.

In general characters, therefore, the sleep of animals and that of plants resemble each other. There are, however, points of great dissimilarity. The position which the leaves assume during the sleep of plants is the same which they have when young, and as yet unfolded. But this position in sleep is not the result of relaxation; for it does not easily admit of being changed, so that the leaves break off in the attempt. Moreover, in the sensitive plants, the position which the leaves have during sleep is the same that they take when irritated. A stimulus applied to a sensitive plant at one spot, in such a manner as to give no mechanical shock to the whole plant,—for instance, the stimulus of heat applied by means of a convex lens,—is propagated gradually to other parts, the leaves closing in succession, according as they lie at a less or greater distance from the irritated point. It appears from the researches of Lindley and Dutrochet, confirmed by Meyer, that two forces are in action in the intumescence at the base of the leaf-stalk, (see p. 867, fig. 55,) one of which tends to raise the leaf, the other to depress it. If the external, or lower side of the intumescence is divided, the leaf is depressed towards that side, as if by turgescence of the opposite side of the intumescence; and division of the internal or superior side produces the opposite result. The elevation and folding of the leaves, which occurs in the absence of light, may be regarded as the effect of the want of the stimulus of light upon the upper surface of the leaves; for in that case, the corresponding part of the intumescence, wanting its proper stimulus, might be supposed to become passive; whilst the inferior half of the intumescence being, perhaps, less dependent on the influence of light, might remain in an active state, and by turgescence elevate the leaf. The same movements, however, are produced by mechanical and chemical stimuli; they cause the leaf to assume the same position as when the upper half of the intumescence is divided. A mechanical shock, therefore, acts exactly as an arrest of action, or like the exclusion of the appropriate stimulus; and it would seem that this disturbance or arrest of action exerts a great influence on one side of the intumescence, and none on the other. We can give no other explanation of the action of stimuli upon the sensitive plants, which would be applicable also to the causes inducing their state of sleep. According to this view, however, the movements of these plants lose all their analogy with the contractions of animal tissues. But the inferior half of the intumescence, the cellular tissue of which remains in a state of turgescence during sleep, may, on the other hand, be compared to that part of the animal organism which continues to perform its functions during the corresponding state in animals.

The sleep of animals is a phenomenon dependent on a change in the

animal part of the organism alone. All the functions of organic life—namely, the processes ministering to nutrition, with all the involuntary movements attending them,—pursue their ordinary course. Even the involuntary movements of the animal system of muscles, such as those of respiration, and many other movements of the same kind, as we shall presently show, do not partake of the repose of sleep. [These are movements depending on the reflex action of the spinal cord and medulla oblongata, parts of the nervous centres which retain their activity during sleep.] The organic system has its periods of remission and rest, but these are not coincident with the sleep of animal life, and are very different for different organs. The heart has its period of rest after each beat; the intestines and uterus have theirs, also, at different times; and the change and new formation of the hairs and feathers show us that the nutritive processes, also, have alternate periods of rest and action. Even the growth of a single tooth, spine, or feather, presents to us a cycle of states, in which the formative process has different degrees of activity. For, during the formation of the shaft of the latter organs, or the fang of the tooth, the nutritive action can be by no means the same as at the time when the crown of the tooth, the point of the spine, or the barb of the feather, is formed. In animals whose hair is knotted, like the vibrissæ of the seal, the nutritive process, on which their growth depends, must consist of a regular succession of alternate remissions and exaltations, since these structures grow only at their root.

All the phenomena of organic life, and, indeed, all the phenomena presented by the animal body, with the exception of the true animal functions which are under the influence of the mind, obey, like the development of the germ, a law of absolute necessity; although, like it, they conform to a well-adapted plan; and the nutrition and maintenance even of the organs of animal life are not dependent on the operations of the mind or intellect. We may, therefore, regard sleep and the waking state, as the result of a species of antagonism between the organic and the animal life; in which the animal functions, governed by the mind, from time to time become free to act, while at other times they are repressed by the organic force acting in obedience to a law of creative nature. It is true that even in the waking state the organs of animal life are under the dominion of the organic force; but the different properties of the muscles and cerebro-spinal nerves, which are the result of organisation, are engaged in actions very different from those of the organising process. In sleep, on the contrary, when these animal functions entirely, or for the most part, cease, the organic processes are almost the only ones which continue; and, during that state, even the organs of animal life are rendered capable of renewed action by the operations of the organising force, which proceed without the consciousness of the animal, though accordant with a well-contrived plan and with reason.

In consequence of all parts of the organism participating to a certain extent in the states of excitement which affect primarily only one part, the waking of the system of animal life, and its consequent increased excitement, must be gradually imparted to those organs which are under the influence of the organic nervous system; and any functions which these organs may perform, in addition to the mere process of organisation, will be in some measure affected. Hence it is that the heart's action becomes rather more frequent at the time of waking than it was during sleep. The radiation or extension of excitement from the animal system to the organic ceases during sleep, and so far the organic part of the body has at that time a remission of action, though in a less degree than the animal system. If the waking state of the animal system is maintained much longer than natural, this extension of excitement from it to the organic system not merely becomes more manifest, (for instance, in the acceleration of the heart's action,) but the great exhaustion of the organised material by continued action is imperfectly balanced by the organising process. Hence the signs of defective nutrition, which soon show themselves when watching is long protracted.

Having considered thus far the nature of sleep generally, we will now study more minutely its phenomena. On the commencement of sleep the senses cease to perceive external impressions, and the play of ideas, and the emotions, are entirely or in greater part silenced. The will ceases to rule the muscles; the eyelids, which experience the sensation of fatigue, are no longer under command; the head droops, and this state of inaction soon extends over the whole animal system of organs.

When sleep is perfect, there is generally a complete absence of voluntary motion; while the involuntary movements of the organic muscles, and those movements of certain animal muscles which are only in part under the influence of the will, such as the respiratory movements, continue; the movements last mentioned merely ceasing to be influenced by volition. The movements of the heart, and the respiratory movements, are somewhat less frequent than in the waking state. The action of some animal muscles is increased during sleep, they being apparently released from some counteracting force which opposed them in the waking state. Such is the case with some of the muscles of the eyes, as well as with the muscles of the extremities in birds which sleep standing on one or both legs. During sleep the eyes have a peculiar position. At that time, as well as in a state of mere sleepiness, both eyes are turned inwards and upwards.* This movement is still more strongly displayed

* [According to Tourtual and Melchior (Müller's Archiv. 1842, p. xxxvi.) the eyes of adult persons in deep sleep, when first opened, are frequently seen to have a diverging position, being directed outwards and upwards, although the pupils are

in disorders of the nervous system ; for example, in epilepsy and catalepsy. This position of the eye during sleep also gives it a very different expression from that which it has in death. The iris is contracted in a person asleep ; and the pupil consequently narrowed ; but on his awakening the pupil always dilates, becoming first, indeed, very wide, and then undulating, until it acquires the mean size which it has in the waking state. (See page 685, 1st edit. and page 736, 2nd edit.) A greater amount of external warmth is required for the body during sleep than at other times ; and immediately after the awakening from sleep there is frequently great sensibility to cold.

When, during sleep, the conception of ideas by the mind does not entirely cease, dreams arise. These are for the most part composed of simple ideas and emotions ; but general notions sometimes come into play, and movements effected by the animal muscles may be combined with the ideas as in the waking state. This condition is "dreaming," as long as the action of the mind is disturbed by something which gives to its operations a character opposed to that of the ordinary conceptions and thoughts of the same person. The ideas conceived in dreams so far resemble those of the waking state, that they may refer to any period of the past life ; just as in our ordinary condition we may look back to all periods of our life, and think at one moment of yesterday, and the next of times years past. If the ideas which occupy the mind during the waking state have a certain degree of persistence, the same ideas will recur in dreams during sleep. The dreams of some persons, on the other hand, refer chiefly to times long past. Many blind people, after they have been some time deprived of sight, cease to dream of visible objects, but their dreams accord with their present mode of intercourse with the external world. Other individuals who have lost their sight, continue through their whole life to dream of visible objects. The important circumstance, therefore, regulating these dreams of visible objects by blind persons, is not the time which has elapsed since the sight was lost ; for Huber, who had been blind since his eighteenth year, when in his sixty-sixth still dreamed of objects which appeared distinctly visible to him, though these dreams referred to the time at which he was possessed of vision. The facts which we learn from such cases are, that the internal parts of the apparatus of vision are alone essential to the production of phantasms, and that ideas recur, which were first conceived previously to the loss of sight.*

In the simplest form of dream the action of the mind is confined to the mere conception of simple ideas, general notions being excluded ;—an at the same time contracted. After the eyes are opened, they gradually assume the straight position, or even become convergent. But they turn outwards again when the eyelids are closed.]

* See Forriep's Notizen. 888, p. 118.

inferior kind of intellectual action, which characterises the mind of brute animals, and also, for the most part, the human mind in the state of intoxication, on account of the disturbance of the organic conditions of the brain in that state. These dreams are accompanied by phantasms (see page 1393). The senses which are thus excited by internal causes may also be called into action by external causes of adequate intensity; but these external impressions, on account of the weakness of the reasoning faculty during sleep, suggest incorrect ideas. A person asleep feels himself in an uneasy position, and believes that he is bound and held down by force. His arms are folded one over the other, and he thinks they are held so by another person. In such cases, the images of persons performing the actions thus conceived in the dream are also produced. Again, the sensation of the urinary bladder being full may be perceived during sleep; but the dreamer, believing that he is awake and out of bed, is led by this sensation actually to evacuate the urine. The increased excitement, of which the sexual organs are from time to time the subject, gives rise to the conception of corresponding images even in dreams. The lamp burning during sleep and the extinguishing of it also exert an influence upon the images conceived in dreams. The cessation of a noise to which the sleeper is accustomed, such as the sound of a mill, excites ideas in the mind in the same way as a sudden noise occurring after previous silence. The serenade and its cessation are both perceived during sleep; but incorrect ideas and phantasms are connected with these sensations, which become interwoven in the web of our dreams.* The predominant emotions of the mind, also, influence the character of the dreams. When the mind is under the sway of depressing passions, the dreams will have a terrible or mournful character.

Sometimes we reason more or less correctly in dreams. We reflect on problems, and rejoice in their solution. But on awaking from such dreams, the seeming reasoning is frequently found to have been no reasoning at all, and the solution of the problem, over which we had rejoiced, to be mere nonsense. Sometimes we dream that another person proposes an enigma; that we cannot solve it, and that others are equally incapable of doing so; but that the person who proposed it, himself gives the explanation. We are astonished at the solution which we had so long laboured in vain to find. If we do not immediately awake, and afterwards reflect on this proposition of an enigma in our dream, and on its apparent solution, we think it wonderful; but if we awake immediately after the dream, and are able to compare the answer with the question, we find that it was mere nonsense. I have, at least, several times observed this in my own case. In dreams in which we

* Various other examples are adduced by Prevost, from the observation of his own dreams. *Biblioth. Universelle*, 1834. Mars. *Forriep's Notizen*. pp. 888, 889.

seem to hold a conversation with other persons, the remarkable circumstance is, that the arguments and counter-arguments, which rise in the mind, are connected with the ideas of the corresponding persons, just as notions are associated with certain signs. It occasionally happens in such dreams that questions are asked and no answer given, because we are ourselves unable to answer them.* Sometimes possible combinations of circumstances are presented to our minds in dreams, with the character of forebodings, and with all the distinctness of reality; and as anything which is possible may become actual, these circumstances may really occur without there being anything wonderful in the matter. For instance, if we are much interested in a person, and regard him with some kind of emotion, know him intimately though not perfectly, and, though we think him honest and sincere, have, nevertheless, conceived it to be remotely possible that he is the reverse; this person may, in our dreams attended with phantasms, appear in situations which show him to be dishonest and insincere: and if it should soon afterwards be proved that such really is the case, the dream appears wonderful, although it is nothing more than a play of ideas excited by a leading thought, which is cherished with the passions of fear and love. Sometimes the sick perceive in their dreams countenances of beneficent persons who advise them to adopt this or that proceeding; and the measures thus suggested occasionally prove successful. Physicians, however, who frequently meet with such prophetic dreamers, have remarked, that they in many instances prescribe for themselves measures which are manifestly injurious, and which, therefore, are not carried into effect.

The indistinctness of the conceptions in dreams is generally so great that we are not aware that we dream. The phantasms which are perceived really exist in our organs of sense. They afford, therefore, in themselves as strong proof of the actual existence of the objects they represent, as do our perceptions of real external objects in the waking state; for we know the latter only by the affections of our senses which they produce. When, therefore, the mind has lost the faculty of analysing the impressions on our senses, there is no reason why the things which they seem to represent should be supposed unreal. Even in the waking state phantasms are regarded as real objects when they occur to persons of feeble intellect. On the other hand, when the dreaming approaches more nearly to the waking state, we sometimes are conscious that we merely dream, and still allow the dream to proceed while we retain this consciousness of its true nature.

It very frequently happens, that in our dream we seem to be in-

* Compare Prevost's Remarks, *loc. cit.*

capable of executing certain movements which we desire to perform. For example, we desire to escape from a danger, but cannot move; here the dream corresponds to a real state of the sensorium, which is in sleep unable to determine the nervous actions necessary for voluntary motion. Some persons, however, have in dreams a certain command of voluntary motion; and, while they sleep and dream, talk confusedly, or, sometimes, even coherently. The same exertion of voluntary power, also, is required by persons sleeping in difficult postures: for instance, by postilions sleeping, as often happens, on their horses; also by birds, which sleep standing, sometimes only on one leg. In fact, it is necessary to constitute sleep and dreams that a very large portion of the ideas which can be called into action in the waking state should be passive; but those ideas which are active may, unless the sleep be very deep, call the organs of motion into activity. The near connection of the different pathological states of sleep with each other is here rendered manifest. The utterance of distinct coherent words during sleep, the rising from bed, and the performance of different acts in that state, are all phenomena of exactly the same kind. The somnambulist is scarcely to be separated from the *somnostatist*,—the bird standing while it sleeps.

The simplest degree of somnambulism is observed in children of excitable nervous system, who, while they yet sleep, become restless, call out, cry, and are quieted and comforted by persons speaking to them, whom they understand, and even recognise when their eyes are open; although, notwithstanding they are thus capable of voluntary movements and susceptible of ideas from external impressions on their senses, they do not for a long time awake from the dream which has alarmed them. In this case the mind is in a certain degree awake, but there are not at first present ideas of sufficient distinctness to restore the mass of ideas, disturbed by the dream, to a state of equilibrium. This state is similar to that of a person just awaking from sleep, with whom we may converse, although he gives confused answers, and confounds what is going on around him with the images and ideas which belonged to his dream.

In more extreme degrees of somnambulism, the dreamer rises and performs all the acts of life under the guidance of those ideas which are in an active state, and of the sensitive impressions connected with those ideas. He performs acts determined by his dream, and when they are attended with danger he is unconscious of it; he crosses, for example, narrow planks, as a child would do, that is not aware of danger, and therefore does not tremble. It is not really very difficult to walk over an inclined plane, if we do not know that it is greatly elevated above the ground; and we should be able to walk over many roofs if they were placed upon the ground. The somnambulist associates only ideas

which bear some relation to those already in action. No other ideas exist for him. He sees and hears; but is disturbed by nothing which is foreign to the train of ideas which constitute his dream, unless he be actually awaked.

Sleep ceases as soon as the susceptibility of the brain for those organic states, which are necessary for the play of ideas and reasoning, is perfectly restored. The condition of the various parts of the body is then again distinctly perceived. But sensations of sufficient intensity produced by external objects, or even strongly excited ideas in dreams, will terminate sleep which is not normally at an end. Strong emotions felt in dreams, such as fear and other passions, very frequently put such an abrupt end to sleep. The emotions here excite actions of the body, as in the waking state, and a stronger and increasing excitement is thus diffused through the system of the sleeper, which at length frees the brain from its fettered state.

As soon as we awake, we analyse the first impressions on our senses, think where we are, whether in this or that chamber, and consequently whether in this or that town; we try next to recollect what time of day it may be, and correct the errors which we may in the first instance fall into with regard to this question. Sometimes the play of the ideas during sleep is so limited, and so completely unconnected with the ordinary ideas respecting the individual existence of the sleeper, that on awaking he has to collect the ideas having reference to his individuality in order to know who he is.

Sleep, in a greater or less degree, as Aristotle correctly remarked, falls to the share of all animals.* Some brute animals even dream; the dog, for example, barks in his sleep. In some, the periods of sleep are less distinct and regular; and this is particularly the case in the cold-blooded animals. They, however, appear to be subject to states analogous to sleep. Frogs, which croak a part of the night during summer, generally become quiet after midnight, especially when the pairing season is passed. Insects and spiders are frequently found in a lethargic or torpid state; and it is probable that all animals in which no regular periods of sleep and waking have hitherto been observed, have an equivalent for sleep in the state of inactivity and rest which they from time to time present.

To return to man.—Persons in whom the organic functions predominate, who are stout and full-blooded, sleep longer and require more sleep; and the contrary is the case with thin persons. Individuals of excitable, but at the same time energetic constitutions, and who are with difficulty fatigued, require less; those of an excitable, but more readily exhausted habit of body, require more sleep. In youth sleep

* *De Somno et Vigiliâ.*

is longer, and is more indispensably requisite, than in old age. This difference seems to depend on the greater predominance of the nutritive organic functions in youth. Hence the great length of time passed in sleep by the new-born infant. This disposition to sleep is constant in the child as long as the organising action finds material in new nutritive matter supplied by food ; and the child awakes when it requires nourishment. In the adult, also, abundant food induces sleepiness, partly by giving increased activity to the organic functions, and thereby disturbing the reaction of the animal functions, and partly by the pressure which the crude and imperfectly assimilated nutriment newly introduced into the blood exerts upon the brain. As causes favouring sleep, we must reckon also the impressions made on the sensorium by general stimulants of the skin, as friction of the surface, baths, &c., and the effects produced on the sensorium from within by sedative and narcotic medicines.

RECENT ADVANCES

IN THE

PHYSIOLOGY OF MOTION IN ANIMALS.

OF CILIARY MOTION.*

SOME additional information has been obtained with regard to the *parts occupied by ciliary epithelium* in the human subject, and in mammalia generally. It is found,† for example, that this variety of epithelium, besides lining the interior of the nasal cavity, and of the frontal and maxillary sinuses communicating with this cavity, is continued up the lachrymal canal into the lachrymal sac, and is also spread over the mucous surface of both eyelids, but not over the conjunctiva covering the eye itself. From the posterior part of the nasal cavity, the ciliary epithelium passes to the upper part of the pharynx, which it lines to about opposite the lower border of the atlas: it is also spread over the posterior surface of the root of the soft palate, and laterally it is continued to the orifice of the Eustachian tube, up which canal it extends into the cavity of the tympanum.

It was until recently believed that the ciliary motion is entirely wanting in the urinary apparatus of Vertebrata. But it has been found by Mr. Bowman,‡ that in frogs a layer of ciliary epithelium lines the urinary tubules just at their junction with the Malpighian capsules; and this observation has been verified by Bischoff,§ Valentin,|| and others. Valentin was able to trace the ciliary motion even within the Malpighian capsules; so also was Pappenheim. In the kidneys of lizards, Kölliker¶ states he has observed ciliary movements along the entire length of the urinary tubules, except at their exit from the gland, and just where they dilate into their terminal extremities within the substance of the organ. No

* Vide Book iv. section 1, Chapter ii. p. 853, of Professor Müller's Elements of Physiology.

† Vide Henle's Allgemeine Anatomie, p. 246 *et seq.* for the best recent account of the localities of ciliary epithelium.

‡ Philosophical Transactions, 1842.

§ Müller's Archiv. 1843, p. 132.

|| Repertorium, b. viii. p. 92.

¶ Müller's Archiv. 1845, p. 519.

trace of cilia has yet been found in any part of the urinary apparatus of Mammalia.

M. Rossignol* finds that the ciliary epithelium along the mucous lining of the respiratory passages, ceases at the vesicular structure of the lung, its place in the vesicles themselves being occupied by simple pavement epithelium, composed of roundish or oval cells. The cessation of the ciliary epithelium at the commencement of the cellular structure of the lung, has been observed also by Mr. Rainey, † who states, however, that the intercellular passages and the air-vesicles in which the ultimate branches of the bronchial tubes terminate, are destitute of epithelium of any kind.

Ecker ‡ has discovered ciliary epithelium in the semi-circular canals of the internal ear of *Petromyzon marinus* (sea lamprey). The cells were of different forms, oval, roundish, flask-shaped, and angular, with nuclei and granular contents. None of the cells possessed more than one cilium. The movements of the cilia were principally of a lashing, fanning kind. This is the first example of a ciliary structure being found in any other part of the auditory apparatus of a vertebrate animal, than the Eustachian tube.

Of the phenomena of ciliary motion.—An interesting observation in regard to the mode of action of the cilia, has been made by Mr. Quekett§ in the case of the gill rays of the mussel, which explains more completely than could otherwise be done, the power possessed by the cilia of propelling fluid or solid particles in any determinate direction. He observed, that besides their ordinary lashing movements, each cilium possesses a kind of rotatory motion on itself, by which it turns on its own axis, through the space of about a quarter of a circle, with a movement very similar to that performed during the *feathering* of an oar in rowing.

Nature of the ciliary motion.—From experiments made on the epithelial cells of the nasal mucous membrane of man, E. H. Weber|| has shewn that the vibratile movements of their cilia are diminished almost to one-half their usual rate by cold, and are sensibly increased by heat. In this as well as in their rhythmic action and its persistence after death, the ciliary movements bear a close analogy to those of the heart. The influence of heat and cold is less manifest on the movements of the cilia, and also on those of the heart, in cold than in warm-blooded animals.

OF THE MUSCULAR AND THE ALLIED MOTIONS.¶

Of the elastic and contractile tissue of arteries.

THE statement made by Professor Müller,** that the middle coat of arteries does not possess any muscular contractility, requires to be

* *Recherches sur la Struct. du Poumon.* Bruxelles, p. 66—8.

† *Medico-Chirurg. Transact.* vol. xxviii.

‡ Müller's Archiv. 1844, p. 520.

§ *Medical Gazette*, May 3, 1844.

|| Archiv. d'Anat. Gen. et de Physiol. Jan. 1846.

¶ Chapter iii. p. 867, Müller's Physiology.

** Physiology, p. 875.

somewhat modified, principally on account of the investigations of Henle,* which have shewn that besides elastic tissue, the middle arterial coat is provided with fibres in all respects analogous to those of organic muscle.

This discovery is one of considerable importance, because it serves to explain what was hitherto unintelligible, the well-known property possessed by arteries, especially by the smaller ones, of contracting, under certain circumstances, to a diameter smaller than that which their elasticity alone could enable them to assume. Although this property has been matter of almost universal observation, yet by few writers has any plausible explanation of it been suggested. The sagacity of John Hunter, unaided by microscopic evidence, led him to conclude that the contraction of arteries was really a muscular act.† Yet this opinion appears to have been lost sight of, for most writers since Hunter's time, including Professor Müller, have attributed the contraction of the arterial coats to a peculiar vital property, to which they gave the name of tonicity or insensible contractility, without being able to refer this property to any definite structure. In the last German edition of the first volume of his work,‡ Professor Müller alludes to this discovery by Henle, and considers it probable that the fibres described by him are the seat of the contractile power of the arteries, though he appears disinclined to admit their muscular nature.

Chemical evidence also in favour of Henle's account has been procured by Dr. Retzius,§ who finds that a solution of the arterial coat in acetic acid is precipitated by cyanide of potassium; this shews that some elements besides cellular and elastic tissues enter into its composition, for the solution in acetic acid of neither of these tissues is precipitated by cyanide of potassium. And that organic muscular fibre constitutes one of these other elements has, since then, been rendered tolerably certain by Dr. F. C. Donders,|| who, by acting upon the middle arterial coat of young sheep with a solution of potash, observed that in two or three hours the fibres of this coat separated from each other, became granular and then dissolved; changes exactly similar to those which he found organic muscular fibres, under like circumstances, to undergo. The existence of muscular fibres in the middle arterial coat is also inferred by the same physiologist¶ from the effects produced upon it by the action of nitric acid and ammonia. When strong nitric acid is applied to a protein-compound, it forms with

* Casper's Wochenschr. May 28, 1840; and Allgem. Anat. 1842, p. 498.

† Works, Palmer's edition, vol. iii. pp. 156—71, comprising his account of the structure of arteries, where (as Mr. Paget has pointed out) abundant proofs are given by Hunter of the existence of muscular power, especially in the smaller arterial branches.

‡ 1841, page 171.

§ Physiol. des Mensch. by Prof. J. Müller, Coblenz. Fourth edition. Vol. i. p. 171.

|| Holländische Beiträge zu den Anat. und Physiol. Wissenschaften, 1846, p. 55.

¶ Op. cit. p. 67.

it what is termed, xantho-proteinic acid, which, with ammonia, produces a yellow xantho-proteinate of ammonia. On applying this test, with the requisite cautions, to the coats of blood-vessels, Dr. Donders found that the middle arterial coat alone assumed the characteristic yellow colour. The other coats, as well as all the coats of veins, remained unchanged in colour.

But the most satisfactory evidence is that furnished by some recent experiments of Ed. and E. H. Weber,* in which they applied the stimulus of electro-magnetism to small arteries. One principal circumstance which induced Professor Müller to deny the muscularity of arteries, was the inability of himself, and of other experimenters who had occupied themselves on the subject, to produce the slightest movements in arteries by means of galvanic and electric stimuli, while in all true muscular tissues these stimuli give rise to manifest contractions. An explanation of the failure of these physiologists, may be found in the circumstance that in nearly all their experiments, the arteries examined were of large size, such as the aorta and the carotids, in which the thickness of the muscular coat is comparatively small. The experiments of the Webers were, on the other hand, performed on the small mesenteric arteries of frogs; and the most striking results were obtained, when the diameter of the vessels examined did not exceed from $\frac{1}{7}$ to $\frac{1}{17}$ of a Paris line. When a vessel of this size was exposed to the electric stream, its diameter, in from five to ten seconds, became one-third less, and the area of its section about one-half. On continuing the stimulus, the narrowing gradually increased, until the calibre of the tube became from three to six times smaller than it was at first, so that only a single row of blood-corpuscles could pass along it at once; and eventually the vessel became completely closed and the current of blood arrested. When the experiment was so conducted, that only a limited part of an artery was exposed to the electric stream, the extent of tube involved in the contraction was equally limited, not exceeding from $\frac{1}{8}$ of a line to a line. The contraction did not ensue the moment the irritation was applied, and it continued for a short time after its withdrawal. The walls of the artery were rendered somewhat thicker at the contracted part, but the narrowing of the canal was proportionally greater than the increase in thickness acquired by the walls. Previous to the complete closure of the artery, the velocity of the stream of blood passing through it, in accordance with hydraulic principles, became considerably accelerated. When an artery was irritated only for a short time, or by a feeble galvanic current, it speedily resumed its former calibre on the stimulus being withdrawn, and again contracted on a re-application of it; but when the irritation was long continued, or the stream very powerful, the portion of the artery narrowed by it lost the power of again contracting, and even dilated, until it became double

* Müller's Archiv. 1847, p. 232, *et seq.*

its former size, forming a kind of aneurism on the trunk of the vessel. When the abdominal aorta and other large arteries were experimented on in the above manner, no decided appearance of contraction ensued; a result agreeing with the observations of the experimenters before alluded to. The electric current produced no contraction of the capillaries, and only a slight one of the small mesenteric veins. One other remarkable circumstance observed in the Webers' experiments may, though out of place, be here mentioned, on account of its novelty and importance; and that is, the speedy arrest and subsequent coagulation of the blood in the vessels, especially the capillaries, exposed to the influence of the electro-magnetic stream. The blood corpuscles adhered unusually to each other and to the walls of the vessels, and by the greater amount of friction thus produced, they became retarded in their onward movement and eventually arrested.

Of the muscular tissue.

Structure of muscle.—Recent microscopic examination of muscles of animal life, appears to have thrown further light on the structure of the ultimate fibrils.* It is found that, with an instrument of good defining power, the border of each fibril appears straight, or nearly so, and that the alternate dark and light particles of which the fibril is composed, have each a quadrilateral and generally a rectangular form. It is found, also, that every bright particle or space is marked across its centre by a fine, dark, tranverse line or shadow, by which the space is divided into two equal parts, and that, "sometimes, also, a bright border may be perceived on either side of the fibril, so that each of the rectangular dark bodies appears then to be surrounded with a bright area, having a similar quadrangular outline, as represented in the figure annexed, and it may therefore be inferred that the pellucid substance incloses it on all sides. In short, it would seem that the elementary particles of which the fibril is made up,



* Dr. Sharpey, in the Fifth Edition of Quain's Anatomy; and Dr. Carpenter in his Manual of Physiology, 1846.

† Fig. 1. "Muscular fibrillæ of the pig, magnified 720 diameters. *a*. An apparently single fibril, shewing the quadrangular outline of the component particles, their dark central part and bright margin, and their lines of junction crossing the light intervals. *b*. A longitudinal segment of a fibre consisting of a number of fibrils still connected together. The dark cross stripes and light intervals on *b* are obviously occasioned by the dark specks and intervening light spaces respectively corresponding in the different fibrils. *c*. Other smaller collections of fibrillæ. From a preparation by Mr. Lealand." After Dr. Sharpey.

are little masses of pellucid substance presenting a rectangular outline, and appearing dark in the centre. Their appearance, indeed, suggests the notion of minute vesicular bodies or cells, cohering in a linear series, the faint transverse marks between being the lines of junction." * On altering the focus, however, the dark spot, as Dr. Sharpey continues to observe, becomes light and appears transparent, though less so than the bright marginal portion. Moreover, when very highly magnified, the dark central part also appears, according to the same observer, marked or constricted in the middle, as if consisting of two separate particles. Whether, therefore, the appearances above described depend on each pellucid particle being really a nucleated cell, and whether the ultimate fibril is to be considered as composed of a single row of such cells opposed end to end, by whose closer approximation to each other the contraction of the fibril is effected, are questions not yet determined.

After repeated examinations of transverse sections of striped muscular fibre, M. Stadelmann† has convinced himself that (as was stated by Mr. Bowman)‡ the tube of the primitive fibre is invariably filled throughout with fibrillæ, and never presents the central cavity described by some writers. A slight appearance of the existence of such cavity is frequently afforded by the dots, which indicate the cut fibrillæ, being much paler at the centre of the fibre than towards its circumference, but they are never so pale as to be invisible.

Cause of the striped appearance of animal muscular fibre.—In addition to the several arguments employed by Professor Müller,§ in favour of the opinion that the transversely striated appearance of voluntary muscular fibre is due to the peculiar structure of the ultimate fibrils of which the fibre is composed, and not to markings on the sheath of the fibre, Mr. Bowman draws attention to another conclusive circumstance, namely, that by successively bringing into focus fresh portions of the depth of a fibre, the first observed striæ become confused, or even vanish, whilst others come into view; shewing that they exist not merely on the surface, but through the entire thickness of the transparent fibres. ||

Relative size of the fibres and fibrils of striped muscle in the fœtus and adult.—The correctness of Mr. Skey's statement,¶ that the primitive fibres of voluntary muscle in the fœtus have a diameter about one-third of that which they possess in adult age, has been recently shewn

* Dr. Sharpey, l. c. p. clxviii.

† Reichert's Bericht in Müller's Archiv. 1845, p. 192.

‡ Philosoph. Trans. 1840, p. 467.

§ Müller's Physiology, p. 880.

|| Philosophical Transactions, 1840, p. 468. The two Webers remain the strongest upholders of the opinion that the transverse markings of the fibres are seated in the sheath; but since their evidence in favour of this view is by no means conclusive, it is not necessary to do more than refer to the article "Muskelbewegung" in Wagner's Handwörterbuch, by Professor Ed. Weber.

¶ Müller's Physiology, p. 881.

by Professor Harting,* who observes that the average diameter of the fibres in the new-born child is to that in the adult as 1:3·64, and that the respective average intervals between the transverse striæ are as 1:1·18. He finds, also, that in the child the distance between the striæ is to the width of the fibre as 1:4·415; in the adult as 1:8·42.

Attachment of muscle to tendon.—Mr. Paget† has recently discovered a new mode of attachment of the ultimate fibres of muscle to their tendons: it was observed in the muscle torn out from the leg of a fly. “Each of three tendons, which are planted in the proximal end of the last but one articulation of the leg, runs in a long, straight, and flat band up the interior of the next superior division of the limb, and receives on each of its edges the broad and somewhat rounded bases of the muscular fibres. These are arranged in a penniform manner, the base of each fibre on one side of the tendon corresponding to the halves of the bases of two adjacent fibres on the opposite side, like the leaflets of the *Pteris* and some other ferns. The fibres are flat, and their extremities, instead of being ensheathed in the tendinous tissue, only adhere to the border of the tendon, and receive on their outer edges one or two finer tendinous filaments, as if for greater fixity.”

Involuntary muscles which are composed of striped fibres.—In addition to the heart, which is the only involuntary muscular organ mentioned by Professor Müller,‡ as having the striped or beaded variety of muscular fibre in its composition, must now be enumerated the lymphatic hearts of reptiles and birds;§ the coats of the stomach and intestines of the tench, and of the stomach in the common roach.||

Of the vital properties of muscle.

The apparent hardness of muscles in the state of contraction has been shewn by Professor Ed. Weber¶ to be caused by the tension which their fibres, as well as their tendons and other tissues, are subjected to from the resistance ordinarily opposed to their contraction. For, when no resistance is offered, as when a muscle is cut off from its tendon, no hardness is perceptible during contraction; indeed, he finds that the muscular tissue is then even softer, more extensile, and less elastic than in its uncontracted state.

Changes in muscle during its contraction.—From what has been learned of late concerning the minute anatomy of striped muscular fibre, and from

* Tijdschr. Voor Natur. Geschied. en Physiol. d. xii. quoted in Mr. Paget's Report on Physiology in 1844–5, p. 11.

† Report on Anatomy and Physiology for 1842–3, p. 6.

‡ Physiology, p. 879.

§ Prof. Stannius in Müller's Archiv. 1843.

|| Prof. Budge, Schmidt's Jahrb. 4, 1847.

¶ Loc. Cit. Art. Muskelbewegung, p. 54.

peculiarities observed in its mode of action, it appears probable that the contraction of this kind of muscle, is effected in all cases simply by a closer approximation of the constituent parts of the primitive fibrils without any change taking place in their general direction, — without the production of any zig-zag inflexions. In addition to the several reasons stated by Professor Müller,* for considering this approximation of particles, as at least one of the modes in which the fibres become shortened, must be mentioned the conclusive observations of Mr. Bowman,† and Professor Ed. Weber,‡ both of whom have examined muscular fibre during its state of contraction. Mr. Bowman's observations were chiefly made on the fibre of muscles which were spontaneously passing into the state of rigor mortis. He noticed that at the contracted part of the fibre, the transverse striæ were approximated closer to each other than elsewhere, and gave to the fibre at such parts a somewhat darker appearance than was presented by the uncontracted portions. Professor Ed. Weber's observations were made on muscular fibres while contracting under the influence of an electric current from a rotatory magnet. He states that, under such circumstances, the contraction may be observed to be attended by a simple shortening and thickening of the individual fibres; and that in this shortening, every part of the contracting fibre participates, so that the outline of the fibre remains uniformly straight, and presents no appearance either of zig-zag inflexions or of the beaded or knotted characters described by Mr. Bowman. The zig-zag inflexions, however, are produced immediately on the cessation of the contraction, and result, as shewn also by Mr. Bowman, from the resistance which the fibres meet, in their endeavour to elongate to their former state, during relaxation. In the case of individual fibres beneath the microscope, this resistance is caused by friction on the surface of the glass. In other cases it probably results from the fibre, though itself relaxed, being prevented from elongating, and its ends thus kept approximated, by the contraction of neighbouring fibres, or by its not being stretched by the action of antagonist fibres. Any of these circumstances would be sufficient to produce the wavy zig-zag appearance frequently observed: and, it may now be considered as tolerably certain, that such an appearance indicates, as Professor Owen and Dr. Allen Thomson originally supposed, that the fibre is in a state of relaxation, and it may likewise be assumed that in all cases the contraction of muscle is effected by the closer approximation of its component particles without the fibres themselves being thrown out of the straight line. It should be stated, however, that Valentin§ continues opposed to this view, and still considers the contraction to be attended by the production of zig-zag flexures.

* Physiology, p. 389.

† Philosophical Transactions, 1840.

‡ Archives d'Anat. Gen. et de Phys. Janvier, 1846.

§ Lehrbuch der Physiol. des Menschen, b. ii. p. 33.

The rigidity of muscles after death.—Much has been written of late on the subject of the post-mortem rigidity of muscles, though in addition to what was stated by Professor Müller,* few new facts of importance have been obtained, beyond some which tend to confirm the general opinion, that the rigidity is dependent upon an actual contraction of the muscular tissue,† and that it does not occur until the muscles have lost their irritability, or their power of contracting on the application of ordinary stimuli. Among other facts in proof of the latter of these circumstances, it has been observed by Dr. Gierlichs,‡ that in frogs, in whom, as in other reptiles, the muscular irritability is very persistent, the rigor mortis is often not established for three or four days after death; that in birds, on the other hand, whose muscular irritability endures but a short time after death, the post-mortem rigidity ensues quickly. Additional proof also has been procured, both by Dr. Gierlichs and other observers, that all circumstances which cause a speedy exhaustion of muscular irritability, induce an early occurrence of the cadaveric rigidity, while conditions by which the disappearance of the irritability is delayed, are succeeded by a tardy onset of this rigidity.

The rigidity of voluntary muscles, from being the most evident, has attracted most attention, and the phenomenon has, until lately, been described solely in relation to this class of muscles, but sufficient evidence has now been accumulated to warrant the conclusion, that the involuntary muscles also are affected by a post-mortem rigidity, which is, in all essential respects, comparable with that seated in the voluntary muscles. And this is true, not merely with regard to those involuntary muscles which, such as the blood and lymphatic hearts, are constructed of striped fibres, but also with regard to the tissues composed of unstriped fibres, such as the muscular coat of the intestines, and the contractile coat of blood-vessels and of the large excretory ducts. The observations of Dr. George Budd§ and of Mr. Paget,|| have proved this in the case of the heart; and the occurrence of the rigidity in the digestive canal has been shewn by Valentin,¶ who found that if a graduated tube be connected with a portion of intestine taken from a recently slain animal, filled with water and tied at the opposite end, the water will in a few hours rise to a considerable height in the tube, owing to the contraction of the intestinal walls. The contraction of the blood-vessels after death was observed by John Hunter, and is now regarded as a well established fact, and one by which the empty state of the arterial system after death is in great measure explained.

* Physiology, p. 890, *et seq.*

† See especially Mr. Bowman in the Philosophical Transactions, 1840; and M. Bruch in Gazette Médicale de Paris, Novembre 1, 1845.

‡ Schmidt's Jahrbuch. Mai, 1844.

§ Medico-Chirurg. Trans. vol. xxi. p. 296.

|| Report on the Progress of Anat. Physiol. 1842-3, p. 6.

¶ Physiologie, b. ii. p. 36.

Are the nerves the sole conductors through the medium of which all stimuli necessarily act on the muscles? *—Some singular results obtained by Dr. E. Harless,† from experiments undertaken for the purpose of determining the relation in which the nervous influence stands towards the irritability of muscular tissue, will, if confirmed, throw doubt on the truth of Müller's opinion that the functional integrity of the nerves ramifying in the muscles is necessary for the excitement of muscular contractions, and that the muscles themselves are not susceptible of the direct action of stimuli. Having exposed rabbits to the influence of the vapour of ether, until they were so far overpowered by it that no movements of their bodies could be excited by means even of galvanism, they were killed by opening the carotid arteries, and the brain and spinal cord exposed. On galvanizing these nervous centres not the slightest movement of the body resulted, but when the galvanic stimulus was applied to the muscles of the trunk, violent contractions at once ensued. Galvanizing the crural nerve produced not the slightest action of the muscles of the corresponding leg, but these muscles were thrown into immediate contraction when the stimulus was applied directly to themselves. Similar results were obtained by galvanizing the nerves and then the muscles of other parts of the body. The result in all cases appeared to point to the conclusion that the muscular tissue possesses within itself an inherent power of contraction, independent of the influence of the nerves distributed to it; for, in these experiments, the nervous system was so far overpowered by the ether, that no amount of irritation of it could excite muscular contractions, while these contractions were at once induced when the irritation was applied to the muscular tissue itself.

* Müller's Physiology, p. 898.

† Müller's Archiv. 1847, p. 228.

VOICE AND SPEECH.*

VERY little new information has been contributed to this department of physiology, since the period at which the second volume of Professor Müller's *Elements of Physiology* was published in this country. A more extended and detailed account of his experiments on the production of the voice, than was contained in the body of his work, has indeed been furnished by Professor Müller† himself, but these details are chiefly explanatory and confirmatory of his former views.

It may be desirable to make some allusion to a highly-ingenious piece of mechanism constructed by M. Faber, a German, and exhibited in this country about two years ago. By means of this curious apparatus, which appears to be by far the most perfect speaking machine yet invented, the peculiarities of the human voice in speaking, singing, and whispering, are very closely imitated. The various difficulties involved in the construction of such an apparatus appear to have entailed many years of close labour upon the inventor; but, as yet, he has not published any account of the methods by which he has so successfully overcome these difficulties.‡

Ventriloquism.—The general correctness of Professor Müller's account of the probable mode of production of this peculiarity of the human voice,§ has been confirmed by M. Colombat,|| who states that by continually practising, in a manner somewhat similar to that pointed out by Professor Müller, he was enabled to attain considerable skill in the production of this variety of voice. The essential mechanical parts of the process consist in taking a full inspiration, then keeping the muscles of the chest and neck fixed, and speaking with the mouth almost closed, and the lips and lower jaw as motionless as possible, while air is very slowly expired through a very narrow glottis; care being taken also, that none of the expired air passes through the nose. But, as observed by Professor Müller, much of the ventriloquist's skill consists in deceiving other senses than hearing.

Falsetto notes.—Professor Müller's explanation of the probable mode of production of falsetto notes has been questioned by MM. Pétrequin and

* Section iii. chap. i. p. 972, Müller's *Physiology*.

† Ueber Compensation, der phys. Kräfte am Menschl. Organ. Berlin. 1839.

‡ About six years ago, indeed, a description of this apparatus, as far as it was then contrived, was given by Dr. E. Schmulz. (Casper's *Wochenschrift*, 1842, p. 785.) But at that period M. Faber does not appear to have brought it to the state of perfection it has now attained. The essential parts concerned in the production of speech, such as the vocal cords, the tongue, and the walls of the mouth and nose are said to be formed of caoutchouc.

§ *Physiology*, p. 1054.

|| *Frorieps N. Notizen*, 1840, No. 290, s. 55.

Diday * who offer an entirely different account of the cause of these notes from any yet published. According to Professor Müller's account,† the falsetto notes are produced by the vibration only of the inner borders of the vocal cords, while in the production of the natural notes, the entire thickness of the cords is thrown into vibration. In the opinion of Pétrequin and Diday, however, the falsetto notes do not result from the vibrations of the vocal cords at all, but merely from those of the air passing through the aperture between the vocal cords, which, during their production, they suppose to assume the contour of the embouchure of a flute. Their arguments in favour of this opinion are founded almost entirely upon peculiarities observed during the production of the falsetto voice. They remark, for example, that it is very common for high-chest notes to pass into the corresponding falsetto notes, if the singer tries to soften them; for at such times the glottis is instinctively constricted to prevent the note from falling, in consequence of the diminished force of the current of air; and if under these circumstances, the vocal cords are rendered more tense in order to the production of a still higher note, the current of air is unable to make them vibrate, but vibrates itself as it passes through the glottis, and a falsetto note is thus produced—the glottis changing from a reed-like to a flute-like instrument. So also in trying to strengthen a low falsetto note it almost invariably becomes a chest note, on account of the vocal cords passing from a rigid to a vibrating state, while the air itself, which is impelled through the glottis, ceases to vibrate. In illustration of their view, they also state, that if while blowing a reed-instrument, such as a bassoon, the reed is taken hold of and held with forceps so as to prevent it from vibrating, its notes—which before resembled chest-notes—assume at once the falsetto character; becoming acute, soft, and whistling.

M. Cogniard Latour‡ has drawn attention to the circumstance that in tongued instruments the number of vibrations, and consequently the height of the tone, is dependent on the weight or other peculiarities of the tongue. He found, for example, that under exactly similar circumstances a tongue of brass vibrated 200 times, a tongue of wood 314 times, and a tongue of elder pith 800 times. Reasoning from this, he believes that in persons with deep voices the vocal chords will be thicker and heavier than in other individuals; and that the deep tone or hoarseness of the voice during a catarrh is owing to the chords being swollen. From experiments with double-tongued instruments he also concludes that the walls of the larynx, as well as the vocal chords, take part in the production of the tones of the voice; and he believes that the small and weak voice of old people is to be ascribed to the inelastic, more or less ossified, condition of the larynx.

* Gazette Médicale, 1844.

† Physiology, p. 1013.

‡ Canstatt's Jahresbericht, Physiologie, 1845, p. 207.

RECENT ADVANCES

IN THE

PHYSIOLOGY OF THE SENSES.

OF THE SENSES GENERALLY.*

Influence of cold and heat on the nerves of sense.—It appears; from some ingenious experiments by Professor E. H. Weber,† that the prolonged application of either heat or cold to nerves of ordinary or special sensation diminishes, or suspends for a time, their power of conveying to the sensorium the effects of impressions made on them. Professor Weber found, for example, that on keeping the tongue immersed for from half a minute to a minute in water heated to about 125° Fahr., and then bringing it in contact with sugar, in powder or in solution, the sweet taste of the sugar was no longer perceived. Moreover, the sense of touch, usually so delicate at the tip of the tongue, was also rendered imperfect. A sensation of numbness was induced in the organ, not unlike that perceived in a limb when “asleep;” and this sometimes remained for about six seconds, or longer. A similar imperfection of taste and touch was produced by immersing the tongue for the same length of time in a mixture of water and broken ice. The cold as well as the hot fluid gave rise to a peculiar sensation of pain in the immersed part: and so similar was the pain produced in each case, that from the sensation alone it was impossible to ascertain whether the fluid used in the experiment was hot or cold. Weber found also that when similar experiments were performed on the lips, the fingers, and other parts, their sense of touch was impaired in the same manner with regard to the perception of heat and cold: for, when two or more fingers were held immersed for a minute or so in water heated to 125° Fahr., or cooled to 32° Fahr., they were found to have lost, for a time, the power of discriminating between a hot and a cold fluid, or solid, body. As in the case of the tongue, so also here, a sense of pain was produced in the fingers during the immersion: this pain, which was the same whether the fluid was hot or cold, is probably to be referred to the trunk, not to the extremities, of the nerve of the immersed part.

He found also that it was not necessary, in order to the diminution or suspension of the sensitive powers of a nerve, that its extremities should

* Book the Fifth, p. 1059 of Müller's Physiology. † Müller's Archiv. 1847, p. 342.

undergo the exposure to heat or cold; for a similar effect was produced when the trunk of the nerve was acted on. The ulnar nerve is the one best suited to illustrate this fact, its trunk lying immediately beneath the surface at the elbow. After immersing the elbow in a mixture of ice and water for about sixteen seconds, Weber observed that a peculiar painful sensation was perceived along the under side of the fore-arm, the wrist, the little finger, and the inner side of the ring finger. The pain had no resemblance to that of cold. On continuing the immersion the pain increased considerably, and eventually became almost intolerable; then it gradually diminished, and the little and the ring fingers became numb, as if "asleep," had no longer the power of distinguishing between heat and cold, and could only imperfectly perceive the contact and pressure of bodies. The sense of smell also would appear, from Weber's experiments, to be for the time suspended, after the cavity of the nose has been filled with either hot or cold water. But the influence of heat and cold is, in this case, less certain, because the action of water alone, independent of its temperature, on the mucous membrane of the nostrils, will for a time suspend the sense of smell.

OF THE SENSE OF VISION.*

Tunics of the eye. The Tapetum.†—As will be mentioned again when noticing the structure of the retina, M. Brücke is of opinion that the staff-shaped bodies composing the so-called membrana Jacobi, probably serve the purpose of returning to the sensitive portion of the retina those rays of light which have traversed the retina, and which are not absorbed by the pigment of the choroid. M. Brücke† believes that this is peculiarly the case in those animals provided with a tapetum; and he considers that the function of the tapetum is to reflect the light on the staff-shaped bodies situated over that part of the retina most used in vision, and so to enable these animals to see, at times when animals unprovided with a tapetum would be in darkness. He observes that all the colours emitted in the dark from the eyes of animals possessed of a tapetum proceed from this structure alone, except the red, which is produced entirely by the blood in the large vessels of the retina and choroid. Hitherto the tapetum has been described as consisting, in all cases, of numerous undulating smooth and transparent fibres, so arranged as to form a fine membrane. But Brücke finds that although this, which he calls the *fibrous* tapetum, exists in most ruminants, Solidungula, and the whale tribe, yet in Carnivora this fibrous structure is replaced by another, composed entirely of smooth, nucleated, somewhat hexagonal-shaped cells; and this he calls a *cellular* tapetum. These cells vary from .0008 to .0028 of an inch in diameter; by transmitted light

* Book the Fifth, section i. p. 1088, Müller's Physiology.

† Page 1119.

‡ Müller's Archiv. 1845, p. 388.

they are yellowish, and their nuclei pellucid; but by reflected light they have a beautiful blue colour, and the nuclei appear as small dark points.

Mr. Cumming* has found that the human eye, when observed under favourable circumstances, appears almost as luminous as the eye of the cat, dog, and other animals provided with a tapetum, to which this luminous appearance has been hitherto supposed to be limited. For the purpose of observing this in the human subject, the person whose eye is to be examined should be placed in a dark room, four or five feet from the half-closed door, with his face towards a light held at an equal distance outside the door. By such a contrivance the reflection may usually be perceived by an observer standing between the screen and the light, and occupying a position as near as possible to the direct line between the source of the light and the eye examined. It varies in appearance from a red livid glare to a bright golden red or burnished brass tint. In some individuals the phenomenon is much more manifest than in others; and in all, the brilliancy of the reflection is proportionate to the intensity of the light used in the experiment. Mr. Cumming is of opinion that the reflection takes place not from the retina, but from the choroid and its pigment. But Mr. Bowman † is disposed to consider it as proceeding from the hyaloid membrane and retina, as well as from the choroid.

The same luminous appearance of the human eye under favourable circumstances has been since noticed also by M. Brücke.‡ He observes that this phenomenon is less manifest in old than in young or adult persons,—a circumstance which he attributes to the greater quantity of choroidal pigment in the eyes of old than of young persons, to the less perfect transparency of the optic media of the eye, and to the more contracted state of the pupil commonly observed in old people. With respect to the source of this red glare, M. Brücke is of opinion that, in man, as in animals, it proceeds entirely from the blood in the vessels of the choroid and retina.

Iris.—The result of experiments recently performed by Signor Guarini,§ taken in conjunction with those obtained by Valentin, and Dr. J. Reid,|| appear to leave no doubt that the movements of the iris are regulated by nervous influence derived from two different sources; the act of contraction whereby the aperture of the pupil is narrowed, being excited by the third pair of cerebral nerves, that of dilatation whereby the size of the pupil is enlarged, being dependent on branches from the cervical spinal nerves, which pass through the superior cervical ganglion of the sympathetic. Irritation of the third nerve, for example, causes contraction of the pupil,

* Medico-Chirurg. Transactions, 1846.

† Physiol. Anatomy of Man, by Dr. Todd and Mr. Bowman. Part iii. p. 51.

‡ Müller's Archiv. 1847, p. 225.

§ Annali Univ. di Med. 1844, and Gazette Médicale, 26 Avril, 1845.

|| Müller's Physiol. Second Edition. vol. i. p. 327.

and division of this nerve is followed by dilatation. Irritation of the superior cervical ganglion, on the other hand, induces dilatation, while its destruction or removal is succeeded by contraction of the pupil. Moreover, after removal of this ganglion on one side, the application of belladonna, or administration of strychnine, is no longer followed by any marked dilatation of the pupil of the corresponding eye, but that of the opposite eye becomes extremely dilated. Besides thus proving the double source of nervous influence supplied to the iris, these experiments appear also to establish the truth of the opinion that dilatation of the pupil is as much the result of an active state of the iris as is its contraction, and that the one act is most probably produced by the radiating fibres of this structure, the other by the circular fibres situated around its inner margin.

The real nature of the fibres of which the iris is principally composed still remains obscure, although little doubt can exist that muscular tissue constitutes some portion of this membrane. Indeed, independent of the proof afforded by the rapidity of the iridal movements, and of their ready excitation on stimulating the nerves by which the iris is supplied, M. Brücke* states that the existence of a large quantity of fibres precisely analogous to those of which the muscular walls of the intestines are composed may be observed in the iris of the human eye, mixed up with the bundles of connective tissue which is frequently described as constituting the sole fibrous texture of this membrane. The existence of these muscular fibres in the iris of many animals, such as ruminants, appears to be doubtful. It is well known that in the iris of birds distinct muscular fibres possessed of transverse striæ are found in abundance; and that in accordance with this anatomical fact a voluntary power is possessed over the movements of this membrane.

The contraction of the pupil which ensues on irritation of the third nerve after death is never so complete as that observed during life, whereas the dilatation resulting from irritation of the superior cervical ganglion is as complete as during life. These facts are considered by M. Guarini to prove that some share in the contraction of the pupil during life should be attributed to venous congestion, resulting from compression of the blood-vessels interlaced among its fibres by the circular portion of the iris during its contraction. This is, probably, the utmost that can be effected by vascular turgescence towards the production of the iridal movements, although by many physiologists the contraction of the pupil has been regarded as almost entirely due to such turgescence, and its dilatation to an empty state of the vessels.

Irritation of the third pair of nerves does not appear in all cases to be followed by contraction of the pupil. Volkmann† found, for example, that although in dogs, after cutting off the head, and removing the brain,

* Müller's Archiv. 1846, p. 377.

† Müller's Archiv. 1845, p. 414.

irritation of this nerve produced contraction of the pupillary aperture, yet in cats and rabbits such irritation, under similar circumstances, was succeeded by considerable enlargement of it. But before any weight can be attached to this statement, which is so entirely opposed to the experience of Valentin, Guarini, and others, it must be verified by the results of further observations.

Transparent Media of the Eye. Vitreous humour.—It has been pointed out by Pappenheim,* Ernst Brücke,† and more especially by Hannover,‡ that the vitreous body of the eye of many animals, as the horse, sheep, dog, and cat, is composed of concentric laminæ of structureless membrane, each of which forms a completely closed sac: the various sacs being enclosed one within the other. But the vitreous body of the human eye is shewn by Hannover to be composed of numerous sectors, the arcs of which are directed to the surface, while the angles converge towards the centre. Each sector consists of a fine textureless membrane derived from the hyaloid membrane, and enclosing the fluid of the vitreous body. The angles of the sectors do not quite reach the axis of the eye, but terminate in a homogeneous structureless substance situated immediately around the axis.

Structure of the retina.—Considerable addition has been made to our knowledge of the minute structure of the retina since the publication of the account given of it by Treviranus, and adopted by Professor Müller.§ It is essential to notice somewhat at length, the most recent information on this subject, inasmuch as it shews to be erroneous the ingenious explanation of the functions of the retina, founded on the supposed termination of its nerve-fibres in distinct papillæ.

These so-called papillæ, which are in reality the cylindrical or staff-shaped bodies composing the membrana Jacobi, are quite distinct from the nervous or sensitive portion of the retina; and, in the opinion of Henle|| and Brücke,¶ belong more to the choroid coat, or at least to its pigmentary layer, than to the retina. A full description of these cylindrical bodies, and of the singular changes which ensue in them shortly after death, has been furnished especially by Hannover** and Henle.†† It will be sufficient here to state that these bodies are transparent, highly refractive of light, and are arranged perpendicularly to the surface of the retina, and that their outer extremities are imbedded, to a greater or less depth, in the pigment of the choroid coat. The only plausible suggestion which has been offered concerning the use of these bodies, is one by Brücke,‡‡ who thinks it not unlikely that they may serve

* Specielle Gewebelehre des Auges, 1842, p. 182.

† Müller's Archiv. 1843, p. 345, and 1845, p. 130.

‡ Müller's Archiv. 1845, p. 471. § Physiology, p. 1122.

|| Allgemeine Anatomie, 1842, p. 662. ¶ Müller's Archiv. 1844, p. 444.

** Müller's Archiv. 1840, p. 340. †† Op. cit. pp. 656 and 783. ‡‡ Loc. cit. p. 444.

to conduct back to the sensitive portion of the retina, those rays of light which, having traversed that membrane, are not entirely absorbed by the black pigment of the choroid; and he supposes that the individual rays returning through these highly refracting bodies may be directed to the same portion of the retina through which they had previously passed, and that their dispersion by mere reflection, which would tend to interfere with the distinctness of vision, is thus prevented. This view is rejected by Volkmann * as improbable.

Within the above described layer of staff-shaped bodies, is placed the expansion of the optic nerve in the form of a fine fibrous membrane, the individual fibres of which radiate from the point of entrance of the optic nerve, and pursue a tolerably straight course towards the anterior margin of the retina. At first the fibres run in distinct bundles, but these, by subdivision and a plexiform interchange of the individual filaments, speedily disappear, and for the remainder of their course the fibres are disposed in the form of a fine fibrous membrane, in which it is difficult to distinguish the several filaments. According to Dr. Todd and Mr. Bowman,† this expansion of the optic nerve appears to be composed of the gray or central portion alone of the individual fibres: the external white substance ceasing at the point where the optic nerve perforates the sclerotica. In the rabbit, indeed, the white substance is continued for a short distance within the globe, but even here the fibres speedily lose their white lustre, and assume for the remainder of their course the grey appearance observed in the fibrous layer of the retina elsewhere.

In defiance of the numerous attempts to determine the mode of termination of the nerve-fibres in the retina, the subject still remains in obscurity. It was supposed that Treviranus had discovered the true arrangement and ultimate disposal of the fibres, each of which was considered to terminate in a rod-shaped papilla on the internal surface of the retina: but it appears to have been clearly proved of late that this view is quite erroneous. The nature of the papillæ, as already observed, is quite different from that described by Treviranus, who, as well as others by whom his view was at once adopted, appears to have overlooked the peculiar structure of the fibrous expansion of the optic nerve. Several later observers, including Valentin, Bidder, and Pappenheim,‡ are of opinion that the fibres terminate in loops at the anterior margin of the retina: Krause§ says he has observed these loops at every part of the retina, both in front and behind: whilst Hannover|| states that they end in free extremities, but never in loops. Nothing, therefore, can at present be stated positively on this point, except that at the posterior part of the

* Wagner's Handwörterbuch, Art. Sehen, p. 272.

† Physiological Anatomy of Man. Part iii. p. 28.

‡ Canstatt's Jahresbericht, 1843, p. 108. § Canstatt's Jahresbericht, 1842, p. 169.

|| Müller's Archiv. 1840.

retina, where the sense of sight is especially developed, no nerve-terminations, looped or otherwise, have yet been found, (except by Krause,) and that, therefore, the opinion that each sensitive point of the retina corresponds to the extremity of a separate nerve-fibre is not founded in fact.

The observations of all who have recently examined the minute structure of the retina, concur in describing the existence of numerous cells and globules surrounding the fibrous expansion of this membrane, and situated chiefly along its internal surface and within the meshes formed by the interlacing of the individual nerve-fibres. These cellular bodies appear to be of different kinds, although, as Henle observes, it is probable that the several varieties met with, are only the same cells in different stages of development. The larger and more perfectly developed cells immediately surround the fibrous layer. By Valentin,* who first accurately described them, they were considered as identical with the ganglion-corpuscles of nervous substance. According to his account, which has since been generally confirmed, these cells when viewed separately are seen to consist of an external transparent membrane, granular contents, and a clear vesicular nucleus, containing a single particle in its centre. These cells lie closely packed together, and by this compression frequently lose their original round form. Valentin states that they are situated only on the internal surface of the fibrous expansion of the optic nerve, and within the meshes of this layer: Henle† makes a similar remark. But Hannover,‡ Krause,§ Pappenheim,|| and others have observed them on the external as well as the internal surface of this layer, which appears, therefore, to be imbedded in cells. The observations of Dr. Todd and Mr. Bowman¶ also, would seem to shew that the cells may occur on both sides. Pappenheim is of opinion that the fibrous expansion consists of two distinct laminæ: and Huschke, adopting this view, as well as the opinion that the cells are situated on both surfaces of the fibrous expansion, thinks that the external stratum of the cells corresponds to one lamina of the fibrous layer, the internal stratum to the other. Henle** discusses at some length, the question as to whether these vesicles should be regarded as analogous to ganglion-corpuscles, and is inclined to doubt the analogy. For, as he observes, beyond their general cellular character, they bear no other resemblance to ganglion-corpuscles; and he is of opinion that they probably constitute a kind of transparent epithelium, which serves to invest the delicate nerves composing the fibrous layer. Very shortly after death these cells break up, and the place which they occupied becomes a confused granular mass, in which are scattered, often in a linear direction,

* Repertorium, 1837, p. 25.

† Allg. Anat. p. 663.

‡ Müller's Archiv. 1840, p. 340.

§ Valentin's Repertorium, 1842, p. 169.

|| Huschke, Eingeweiden und Sinnes-org. des Menschl. Körpers, p. 719.

¶ Op. cit. p. 29.

** Op. cit. p. 665.

numerous oil-like globules, which are probably the nuclei of the disintegrated cells.

Between the above-described cells immediately surrounding the fibrous portion of the retina, and the internal surface of this membrane, other globular particles are found, smaller than the last.* They somewhat resemble blood-corpuscles, in form and size, and lie thickly together, but without adhering either to each other, or to the larger corpuscles. As was before observed, they are considered by Henle to be an early stage of development of the large cells, probably the nuclei; many, indeed, appear to be already surrounded with a delicate cell-wall, within which is a faintly-granular material. These cells occasionally present a very close resemblance to epithelium.†

Formation of images on the retina.—It has been found by Volkmann‡ that in order to perceive the image of a bright object depicted on the retina of a human eye, it is not necessary to make an opening into the sclerotic and choroid coats, as formerly directed,§ for it can be perceived through these tunics almost as distinctly as through the transparent tissues of the eye of the white rabbit or other albino animal. Moreover, he has found that this image may be observed in the eye even of a living person. For this purpose an individual should be selected in whom the eyes are large and prominent, and whose sclerotica possesses an unusual degree of transparency, as denoted by the bluish tint which it presents through the conjunctiva. When such an eye is directed as far outwards as possible, and a luminous object is then placed at the outside of it, at an angle of from 80° to 85° , the image of this object may be detected at the inner angle of the eye, appearing through the transparent sclerotica. Sometimes this image is so distinct that the inverted position in which the object is depicted on the retina may be clearly discerned.

Adaptation of the eye to vision at different distances.||

The power possessed by the eye of so adapting itself as to obtain a distinct view of objects placed at various distances from it, and thus of providing against the errors in vision which would otherwise result from the varying focal distances at which the perfect image of the objects would be formed on the retina, still continues to occupy the attention of physiologists; and although many ingenious attempts, both formerly and of late, have been made to account for this highly important property of the eye, no completely satisfactory explanation of it has been hitherto afforded.

* Valentin, Henle, &c. Op. cit.

† Klenke, in Canstatt's Jahresbericht for 1842, Physiologie, s. 315.

‡ Wagner's Handwörterbuch, Art. Sehen, p. 286.

§ Müller's Physiology, p. 1131.

|| Müller's Physiology, p. 1136.

Professor Müller has well discussed the whole of this subject,* and the additional observations which have been made since the period at which his account was published, consist less of new hypotheses than of arguments and fresh facts tending either to support or controvert one or other of the several explanations considered at length by him. In further refutation, for example, of the doctrine according to which this power of adaptation of the eye is attributed to an elongation of the entire globe, effected by compression of it through the action either of the four straight, or of the two oblique muscles of the eye, Hueck† states, that owing to the firmness and resistance of the sclerotica in the perfectly fresh eye, he was unable, even by considerable circular pressure, to produce any appreciable elongation in the globe of fresh eyes from a bird and from a cat; nor in consequence of such pressure did any remarkable alteration in the distinctness of an image formed on the retina ensue. He endeavoured also to ascertain the effects of such pressure on the eye of the living human subject, and for this purpose hollowed out a piece of cork, and adapted it to the globe of the eye in such a manner that he could thereby compress it against the inner wall of the orbit: and the result of such compression was the production of but a slight change in the distance of distinct vision.

The increased convexity of the cornea, which was said to be one of the important changes effected by compression of the eye, and on the occurrence of which its power of adaptation to the perception of near objects was supposed to depend, could not be detected by Hueck. He attentively watched the cornea while the sight was changed from an object thirty feet distant from the eye to one only seven inches distant, but beyond the movements resulting from respiration and from the pressure of the orbicularis muscle, he could not perceive any change in the cornea; no protrusion, and no sinking. This agrees with the observations of Dr. Young, who also was unable to perceive any such change as was said by Sir E. Home and others to take place.‡

Another mode in which the action of the recti muscles was supposed to aid the eye in adapting itself to the distinct vision of objects at different distances was by retracting the globe and compressing it against the posterior part of the orbit, whereby the axis of the eye would, it was sup-

* Physiology, pp. 1136–50.

† Ueber die Bewegung der Krystallinse, 1839, noticed by M. Tourtual in his Report on the Progress of the Physiology of Vision. Müller's Archiv. 1842, p. iii.

‡ Müller's Physiology, p. 1143. Mr. Smee (Vision in Health and Disease, page 16), acting upon the suggestion made by Professor Müller, has watched the images formed by reflection on the cornea, and states that when the eye looks at distant objects these images become smaller than when it is directed to near objects; if this change in size really ensues (though it is difficult to make quite sure about it) it would certainly seem to indicate that the convexity of the cornea undergoes some alteration at such times.

posed, be shortened, and the focal point of the rays from distant objects thus be made to impinge on the retina instead of falling short of it, as would be the case if some such adapting power did not exist. According to this view of the action of the muscles, therefore, their effect would be to render distinct the perception of distant objects only: but Hueck gives further proof that, as was observed by Professor Müller,* it is in looking at any near objects that we make an active change in the condition of the eye; the vision of distant objects being attended by a comparatively passive state of the organ. The existence, however, of any such alteration in the form of the eye by the action of the recti muscles is quite improbable, for, owing to the presence of a yielding mass of fatty tissue at the posterior part of the orbit, a very considerable, and, therefore, quite manifest, retraction of the globe must take place before the shortening of the axis of the eye supposed by this hypothesis could be effected. No such retraction, however, is observed to take place during any part of the act of vision. Indeed, as observed by Volkmann,† we do not seem to possess sufficient power over the recti muscles to produce the combined action of all the four at one time; and except by such combined action, either of all four, or at least of two opposite ones, retraction of the eye-ball could not be effected. There does not exist any obstacle to the retraction of the eye within the orbit, could the simultaneous action of the recti muscles be induced at will; this was shewn by Volkmann, who galvanised the third pair of nerves in animals recently slain, and observed well-marked retraction of the eye to ensue in consequence. Another circumstance mentioned by Volkmann,‡ to shew how little, if any, share is taken by the recti muscles in adapting the eye to vision at different distances, is that injury of the third pair of nerves, whereby paralysis of three of the recti muscles is produced, is not followed by any material disturbance of the power of adaptation; while, on the other hand, certain pathological conditions sometimes occur, in which, without any alteration in the functions of the muscles of the globe, the eye suffers a temporary impairment, or even permanent loss of this power.

In addition to the many proofs already afforded that the action of the *iris* is not the force concerned in adapting the eye to various distances of vision, and that alterations in the width of the pupil may take place without any corresponding change in the distinctness of objects under view, Hueck states that without altering the direction of the axes of his eyes or the quantity of light admitted, but merely by fixing his attention on a side object, he was able to widen his pupils as much as one half more than their former diameter, without there ensuing any indistinctness of the object towards which the eyes were directed. He observes also that the inefficiency of the iris, in this respect, is demonstrated by the fact that

* Physiology, p. 1144.

† Art. Sehen, in Wagner's Handwörterbuch, p. 301.

‡ Loc. Cit. p. 302.

individuals in whom the iris is wholly wanting have usually perfect vision for near as well as distant objects.

Volkman and Hueck both agree in considering that in its quiescent state the eye is adapted to the vision of objects situated at the furthest point of distinct sight, and not, as has been generally supposed, of those situated about midway between this and the point of distinct vision nearest to the eye. In this case, therefore, in order to accommodate itself to the vision of an object placed at any distance within the furthest point of sight, the eye will require but one act, that, namely, of increasing its focal distance in proportion to the nearness of the object under view: no act will be requisite to adapt it to the perception of distant objects, for, in reverting to its state of rest, it at once resumes its capacity for distant vision, and retains it so long as its quiescent state continues. In proof of this opinion Volkman observes, that in the state of rest the axes of the eyes are directed towards a point even considerably beyond the most distant point of distinct vision, and that, since changes in the position of the axes usually correspond with changes in the adaptation of the eyes, it is improbable that the meeting of the axes beyond the most distant point of vision should coincide with an adaptation of the eyes for an object on this side the point. According to Hueck this view will also explain the distinct formation of the image of distant objects on the retina after death; as also the far-sightedness induced by the action of hyoseyamus and of belladonna.

The tendency of most of the late observations on the subject of the accommodating power of the eye is in favour of the view proposed by Kepler, and countenanced by Professor Müller,* that this power is mainly due to some alteration either in position or form, or in both, undergone by the crystalline lens. The arguments stated by Hueck in favour of this view are, first, that if the eye is watched attentively from the side, the iris will be observed to be bent forwards in the middle and approximated closer to the cornea when a near object is viewed, and to become flattened again when the sight is fixed upon a distant object. And, secondly, that when the fresh eye of a dog is removed and placed before a window, so that a distinct image of the window-frame through an opening in the sclerotica, and an indistinct one of a smaller object, such as a key, held nearer to the eye, are perceived, the latter may be rendered distinct, and the former indistinct by drawing the lens forward with a needle inserted through the margin of the cornea. With respect, however, to the mode in which this supposed approximation of the lens towards the cornea during the vision of near objects is effected, different explanations still continue to be offered. Burow† adopts that view, according to which the forward movement of the lens is attributed to vas-

* Physiology, p. 1150.

† Tourtual's Report (page xi), in Müller's Archiv. 1842.

cular turgescence of the ciliary processes ; and in this Tourtual agrees with him. Mr. White Cooper * and Mr. Alfred Smee,† who have lately written on this subject, also advocate the same view. In Mr. Smee's opinion turgescence of the ciliary processes will produce pressure outwards against the cornea, and inwards towards the vitreous body, and the result of this will be that the lens is carried directly forwards ; its subsidence to its former position will ensue passively on the cessation of the turgescence. But the most probable explanation, and one which has received the most support, is that the forward movement of the lens is effected by a contractile, probably muscular, tissue, situated in the parts surrounding the margin of the lens. According to many of the older observers, such a contractile tissue was supposed to exist in the lens itself ; and this opinion was formerly entertained by Volkmann, who of late, however, has seen reason to abandon it. Hueck, who has especially occupied himself with the consideration of this subject, states that the contractile tissue by which the lens is acted upon is situated along the anterior and inner portion of the ciliary body, and consists of transversely arranged, firm, probably muscular fibres, connected together in a kind of network. Brücke's‡ account corresponds very closely with this, though he considers the whole ciliary body to be composed of muscular fibres, which pass backwards to be inserted into the choroid coat. In birds, and many amphibia, he describes these fibres as being of the striped variety ; but in man and mammalia they are unstriped. Huschke is of opinion that on the contraction of these fibres, which ensues during the vision of near objects, the fluid contents of the canal of Petit are compressed against the margin of the lens, whereby the lens itself is lessened in diameter, and becomes more curved forwards on its anterior surface. Brücke, on the other hand, considers that the action of these fibres will be to draw the choroid, and with it the retina closer around the vitreous body so as to compress it [and thus probably push the lens forwards, so as to assist in the vision of near objects]. On relaxation of these fibres the choroid regains its former position by the recoil of a layer of elastic fibres, which, according to Brücke, are situated between the ciliary body and the choroid. Dr. Clay Wallace,§ who was among the first to describe these muscular fibres of the ciliary body, considers that they act in adapting the eye to near vision by compressing the ciliary veins, and so producing the turgescence of the ciliary processes, which he, as well as the other observers already mentioned, recognizes as the cause of the accommodating power of the eye. According to Wagner,|| the ciliary processes as well as the ciliary body, contain contractile fibres, which have all the characters of those of organic muscle : by the action of these fibres, Wag-

* On Near and Distant Vision, 1847, p. 195.

† Vision in Health and Disease, &c. 1847.

‡ Müller's Archiv. 1846, p. 370.

§ London Medical Gazette, 1842. Dec. 16 and 23.

|| Lehrbuch der spezielle Physiologie, 1843. Second edition, p. 405.

ner considers that the lens may be drawn forwards as well as perhaps somewhat compressed laterally. Wagner's account of these fibres of the ciliary body and processes is also corroborated by the researches of Mr. Todd and Mr. Bowman,* who describe the fibres as radiating backwards from the junction of the sclerotic and cornea, and spreading over the outer surface of the ciliary body, the more superficial ones being inserted into the posterior part of this body, while the deeper ones seem to dip behind the iris to the more prominent parts of the ciliary processes which approach the lens. These fibres, although they belong to the unstriped variety of muscle yet seem to be analogous to those of the ciliary muscle in birds, which occupy the same position, but are of the striped kind. The contraction of these fibres will, according to Dr. Todd and Mr. Bowman, have the effect of advancing the ciliary processes, and with them the lens to which the processes are attached with considerable firmness, towards the cornea. One difficulty, however, which must ever present itself against the view that the contraction of these various fibres situated about and within the ciliary body—belonging, as they are said to do, to the class of involuntary muscles—constitutes the exclusive, or even the principal, condition by which the eye is enabled to accommodate itself to the distinct vision of objects at various degrees of closeness, is the circumstance that this accommodating power can by many persons be effected by a voluntary effort, quite independent of any alteration in the direction of the axes of the eyes. It cannot but be concluded from this circumstance either that there exist some other conditions than the contraction of the above described muscular fibres, by which the eye can adapt itself to distances, or else, which is very improbable, that a voluntary and tolerably rapid movement can be effected by the action of involuntary muscular fibres. The same difficulty occurs also in referring the explanation of the adapting power of the eye to vascular turgescence of the ciliary processes.

An entirely different explanation of the power of adaptation in the eye has been offered by M. Sturm.† This explanation is founded chiefly upon the result of Chossat's‡ measurements of the eye of an ox, which shew that none of the refracting media of the eye have a spherical form, but that the anterior surface of the cornea and the two surfaces of the lens represent segments of different ellipsoids. From such a conformation of the refracting bodies it will follow that the several rays of a cone of light proceeding from an object placed before the eye will not be concentrated to a single focal point at a definite distance behind the lens, as is commonly supposed, but will intersect each other at different distances, within certain limits. And in any plane within these limits, although the rays are spread over a minute surface, instead of being collected to a point, yet

* Op. cit. Part iii. p. 27.

† Comptes Rendus, tom. xx. pp. 554 and 761.

‡ An. de Chimie et de Physique, tom. x. 1819.

the majority of them are situated at the centre, and will be capable of representing an image of the object regarded. Hence it results in Sturm's opinion that whether the object be approximated closer to or removed further from the eye, without any change in the eye itself, perfect vision of it will be obtained, the retina being still within the limits of the intersection of the rays. If, however, the position of the object before the eye be so much altered that none of its rays can cross each other at the retina the image of it will be indistinct.

Professor J. D. Forbes* has lately expressed an opinion that the adjusting power of the eye is due to the variable density of the crystalline lens. It is usually considered that the great difference in density between the central and peripheral portions of the lens is intended for the purpose of correcting the effect of spherical aberration of the rays of light, but Professor Forbes remarks that there is no need for the existence of such correction; for, as already mentioned, it has been shewn by M. Chossat's measurements,† that the lens does not represent the segment of a sphere, but of an ellipsoid, in which the surfaces have a curve of *no aberration*, and will consequently require no variation in density of the refracting medium. This Professor Forbes regards as a proof that the variable density of the lens is intended for some other purpose than to correct aberration: and this purpose he conceives to be the focal adjustment of the eye. In order to render the lens available for the production of this object, he believes that in regarding a near object the four recti muscles of the eye are simultaneously and voluntarily set in action, whereby the eye is drawn back into the socket, and that the pressure thus resulting upon the humours of the eye is propagated to the lens, which, owing to the inconsiderable density and elasticity of its peripheral parts, is altered from its flattened ellipsoidal form to a somewhat more spheroidal mass, and one possessed of greater density than before. In this manner its converging powers will be increased, and distinct vision of a new object thus be effected. Against this ingenious view, however, must be repeated the several objections, which have been already stated at page 22; namely, the absence of any firm resisting medium at the posterior part of the socket, which is chiefly occupied by fat: no appearance, during the vision of near objects, of any retraction of the globe of the eye, which probably must ensue before the action of the recti muscles could exert such compression on the lens as to produce the effect supposed by Professor Forbes; and lastly, the objection urged by Volkmann against the probability of any share in the adjusting property of the eye being taken by the recti muscles, namely, that we do not appear to possess the power of voluntarily exciting all the recti muscles to simultaneous action.

From the consideration of these several opinions offered in explanation

* Transact. of the Royal Society of Edinburgh, 1845, part i. † Ann. de Chimie, i. c.

of the remarkable property possessed by the eye of accommodating its visual powers to the distinct perception of objects placed at such various distances from it, the conclusion naturally forces itself upon the mind, either that we still remain unacquainted with the real cause of this singular property, or, which is more likely true, that it is the result of two or more of the above-mentioned conditions acting together. For by thus attributing to several of these conditions a certain relative share in the production of this result, it is easy to perceive how by their united agency, they may effect that alteration in the interior of the eye on which the focal adjusting power of this organ depends, but which, individually, it is improbable they could induce.

The range of distance through which the human eye is capable of adapting itself to distinct vision, has occupied the attention of Hueck and Burow.* Both observers have found that this distance varies in different individuals, whose sight in other respects may be quite perfect; and Burow observes that, as a rule, there is a close correspondence between the position of the most distant and that of the nearest point of vision, so that the one being determined, the other may be inferred with tolerable accuracy. The distance between the two bears a close relation also to the refractive power of the eye, being less in proportion as the latter is greater, and *vice versâ*. According to Volkmann, the eyes of different individuals likewise vary in their comparative refracting power over the circumferential and central rays of light; in some persons the former rays are refracted more powerfully than the latter, while in others the reverse is the case. A series of experiments conducted by Gruber,† led him to the conclusion that even in the same individual, the two eyes have frequently dissimilar distances for distinct vision, so that an object which apparently is regarded by both eyes, is in reality distinctly seen only by one, the focal distance of the other eye requiring to be altered, in order that it likewise may have a clear sight of the object.

In a case of singular congenital malformation of the iris in which the transverse diameter of the pupil was considerably greater than the longitudinal, the latter not exceeding in its middle or widest part, half a line, in a moderate light, and the entire pupil completely closing in a strong light, Tourtual‡ found, among other peculiarities of vision, that objects having a transverse direction could be perceived at a greater distance than those which were longitudinal. This, and other circumstances, led him to the conclusion that a transverse pupil will have the effect, like the opening between the eyelids, of increasing the distinctness with which distant objects are perceived.

* Beiträge zur Physiol. und Physik des mensch. Auges, 1842. Noticed by Tourtual, Loc. Cit. p. vii.

† Canstatt's Jahresbericht. 1847, p. 194.

‡ Müller's Archiv. 1846, p. 346.

*Action of the retina and of the sensorium in vision.**

Under this head may be mentioned some of the highly interesting particulars of a case in which a well-informed youth, blind from birth, had the sight of one eye restored by a successful operation performed by Dr. Franz.† The patient had congenital cataract of both eyes, with internal strabismus to such a degree, that nearly one half of each cornea was hidden by the inner canthus. The right eyeball had atrophied in early life, in consequence of inflammation ensuing after the operation of keratonyxis, and became completely amaurotic. The left retained sensibility to the impression of light, but had no power for the perception of objects. At the age of seventeen the operation for cataract was successfully performed on the left eye, and the sensitiveness of the retina was at once made evident by the blaze of light perceived when the eye was opened. On the third day after the operation, the eye was again opened, when the patient perceived an extensive field of light in which no object could be distinguished: everything appearing dull, confused, and in motion. During the next few days, at the times of the eye being open, nothing was seen except a number of "opaque watery spheres, which moved with the movements of the eye, but, when the eye was at rest, remained stationary, and then partially covered each other." The spheres gradually became more transparent, and the patient was enabled to perceive, through them, as it were, a slight difference in surrounding objects: but, owing to the pain produced by the light, the eye could not be kept open long enough to allow of a distinct visual impression of any object being perceived. The appearance of spheres had entirely vanished at the end of two weeks. When the intolerance of light had so far abated that the patient could, without pain, regard an object for a sufficient time to gain a clear idea of it, he was able to perceive and correctly describe vertical and horizontal lines, triangles, spirals, and other black figures drawn on paper and placed before him. His perception and discrimination of different colours placed on a black ground were equally correct. An answer to the well-known question put by Mr. Molyneux to Locke‡ was next experimentally sought. A solid cube and a sphere, each of four inches diameter, were placed before the patient at the distance of three feet, and on a level with the eye. "After attentively examining these bodies, he said he saw a *quadrangular* and a *circular* figure; and, after some consideration, he pronounced the one a *square*, and the other a *disc*. His eye being then closed, the cube was taken away, and a disc of equal size substituted, and placed next to the sphere. On again opening his eye, he observed no difference in these objects,

* Müller's Physiology, p. 1162.

† Philosophical Transactions, 1841, pp. 59—68.

‡ Müller's Physiology, p. 1176.

but regarded them both as discs. The solid cube was now placed in a somewhat oblique position before the eye, and close beside it a figure cut out of pasteboard, representing a plain outline prospect of the cube when in this position. Both objects he took to be somewhat like flat quadrates. A pyramid placed before him, with one of its sides towards his eye, he saw as a plain triangle. This object was now turned a little, so as to present two of its sides to view, but rather more of one side than of the other: after considering and examining it for a long time, he said that this was a very extraordinary figure; it was neither a triangle, nor a quadrangle, nor a circle: he had no idea of it, and could not describe it: 'in fact,' he said, 'I must give it up.' An example of the close association which exists between the sense of touch and that of sight in enabling the mind to form a correct idea of an object, is afforded in the statement of this patient, that, although, by the sense of sight he could detect a difference in the cube and sphere, and perceive that they were not drawings, yet he could not form from them the idea of a square and a disc, "until he perceived a sensation of what he saw in the points of his fingers, as if he really touched the objects." When he took the sphere, cube, and pyramid, into his hand, he was astonished that he had not recognized them as such by sight, being well acquainted with them by touch.

When the patient first acquired the faculty of sight, all objects appeared much nearer to him than they really were, and much larger than he had supposed them to be from the idea obtained by his sense of touch. He also saw everything perfectly flat: and, by the sense of sight alone, could obtain no correct idea of a solid or projecting body. When, by the division of the internal rectus muscle of both eyes, effected about two months after the operation for cataract, the strabismus was cured, all objects were, for a considerable time afterwards, seen much to the right of their real position. These various circumstances shew how large a share is taken by the operations of the mind in association with the impressions received on the retina, in forming a correct estimate of the form, size, distance, and position of an object presented to the sight, and how difficult it is in the case of the educated eye to say "what belongs to mere sensation, and what to the influence of the mind,"*

Physiological colours produced by contrast.—Some interesting observations with respect to the formation of complementary colours, have been published by Dr. Tourtual.† On moving rapidly to and fro a pen-knife in front of the white glass shade of a burning lamp, Dr. Tourtual observed that it assumed a beautiful blue colour, the distinctness of which was in direct proportion to the rapidity of the movements. On the cessation of these movements the colour changed into black. The introduction of a

* Müller's Physiology, p. 1166.

† Canstatt's Jahresbericht, 1845, p. 208.

second light prevented the occurrence of the phenomenon. The blue colour was considered by Dr. Tourtual to be complementary of the reddish-yellow colour of the lamp; and he was led by the circumstance to undertake some additional experiments on the subject. On placing a strip of black silk, about three lines broad, on a piece of orange-coloured cloth, and on directing the axes of both eyes towards it at a moderate distance, and in clear daylight, the distinction between the two colours was clearly seen. But on closing the left eye, and gradually approximating the object towards the right eye, whose direction and point of adaptation remained unaltered, a bright margin appeared around the black silk, and the silk itself assumed a dark blue colour. When, in a similar experiment, the black silk was placed on a purple ground it assumed a green colour, on a violet ground a yellow colour, and so on; the colours assumed being always complementary of that on which the silk was placed. A similar phenomenon was observed when, instead of the black silk, a strip of white paper of the same breadth was employed. The change of colour may be observed also, when, instead of altering the position of the object, the eye be directed to a point about an inch on one side of the black stripe; or when the one or both eyes are made to accommodate themselves to distant vision. The size of the pupil has no direct influence on this phenomenon; it appears, in the opinion of Tourtual, to arise from indistinctness of vision alone.

An interesting fact in relation to complementary colours, has also been noticed by M. Brücke.* He found that the transmitted portion of the rays of light falling on any given part of the fibrous tapetum of animals, possessed a colour exactly complementary of that reflected by the same part of the tapetum. The various colours reflected by the tapetum (not including the *red*, which is due to the blood in the vessels of the retina and choroid) are yellow, merging into orange, yellow itself, green, blue, and blue merging into violet; those transmitted are all complementary of these, viz., violet merging into blue, violet itself, red, orange, and orange merging into yellow.†

Relation of non-luminous rays to the eye.—Several very ingenious experiments have been performed by Ernst Brücke,‡ to determine whether the chemical and calorific rays of light are transmitted through the transparent media of the eye as well as the luminous ones. To ascertain this with regard to the chemical rays, those namely which are situated outside the violet, he took advantage of the property which these rays possess of changing the colour obtained from guaiacum wood first to a bright green, and then to a deep greenish-blue tint. Having coloured a small porcelain plate with tincture of guaiacum and dried it in the dark,

* Müller's Archiv. 1844, p. 449.

† For an account of the Simple and Complementary colours, see Müller's Physiology, p. 1103.

‡ Müller's Archiv. 1845, p. 262.

he allowed light to fall on it, after passing through the fresh lens of an ox's eye. The result was, that instead of being deeply coloured, as it would have been by ordinary diffused light, it scarcely underwent any change. The experiment was then performed with the cornea as the transparent medium, then with the vitreous humour, and lastly with all the three media together. And the general results which he obtained were, that the lens, instead of allowing the chemical rays to pass through it, absorbs them very largely; that the cornea and the vitreous humour absorb them also, though in a less degree; and that with the three media together, the absorption is almost complete. In a more recent set of experiments,* he obtained equally satisfactory results by employing photographic paper as the sensitive surface on which the rays of light were allowed to fall after traversing the transparent media of the eye. The results of these latter experiments proved, at least, that those rays situated to the outside of the violet are arrested, although the paper was deeply blackened by the violet ray itself.

To determine the same point in regard to the calorific rays, M. Brücke made use of a thermo-electric apparatus, and on allowing light to fall on this through the transparent media of the eye, he observed that its needle underwent no change; shewing, therefore, that very little, if any, of the calorific portion of a ray of light is transmitted through the eye.

Binocular vision.—A somewhat different explanation of the mode in which the reflection of two different views of a solid object in the stereoscope † produces in the mind the idea of a single object similar to the original, has been proposed by Tourtual,‡ who details the results of numerous experiments in support of it. But in this explanation there appears to be little really at variance with the one afforded by Professor Wheatstone, and in the results of the experiments nothing which can invalidate the main conclusion derived from Professor Wheatstone's philosophical researches, namely, that our conviction of the solidity of an object, or of its projection in relief, is due, in great measure, to the circumstance of corresponding portions of the two retinae receiving the impression of a different view of the object—the one view as seen by the right eye, the other by the left—whereby an exact counter-part of the original is produced. Tourtual objects to this view, and considers that the fact of the solidity of a near object being distinctly realized by one eye alone, affords a conclusive proof that the visual perception of an object of three dimensions, is an operation of the mind, and is not necessarily dependent on the formation of two images of this object on the retinae. Volkmann and Brücke also appear to agree with Tourtual in the opinion that the perception of a solid object in the

* Op. Cit. 1846, p. 379.

† Müller's Physiology, p. 1205.

‡ Report in Müller's Archiv. 1842.

field of vision does not result from a coalescence of two perspective views of it depicted on the retinae, but that the single idea thus excited, is the product entirely of a mental operation, by which a single form is created from the two images presented to the retinae. The distinction is one obviously unimportant, and has probably arisen from these observers having under-estimated the amount of mental influence admitted by Professor Wheatstone to be concerned in the true visual perception of a solid body.*

OF THE SENSE OF HEARING.†

Movements of the small bones of the ear.—In an account of the movements undergone by the small bones of the ear, and their utility to the sense of hearing, Ed. Weber‡ offers an explanation of the rounded appearance presented by the external surface of the membrane of the fenestra rotunda when the membrana tympani is pushed inwards after death, and of its concave appearance when the membrana tympani is drawn outwards. He observes that the articulation between the head of the malleus and the body of the incus is such that the former bone cannot be moved alone by the membrana tympani, but that both move together as one bone. He states that their axis of movement is the line drawn from the slender process of the malleus to the short process of the incus; on these two processes adherent to the wall of the tympanum the bones turn, as on a pivot. Thus it happens that when the membrana tympani is pushed inwards, the stapes is pressed within the fenestra ovalis by the long process of the incus; when, on the contrary, the membrana tympani is drawn outwards, the stapes is carried out from the fenestra ovalis. The stapes could not exercise these movements completely if the cavity of the labyrinth was bounded entirely by firm and unyielding walls, for the fluid within it is almost incompressible. But by the pressure of the fenestra rotunda this difficulty is avoided. The fluid which fills the vestibule communicates with that in the cochlea, particularly with that of the scala vestibuli, which again freely communicates with that of the scala tympani; so that when the membrane of the fenestra ovalis is pushed inwards towards the vestibule, the consequent pressure on the contained fluid will be communicated to the membrane of the fenestra rotunda, which will be pushed outwards. In this way the movements of the membrana tympani produce indirectly the flux and reflux of the fluid of the labyrinth from the fenestra ovalis to the fenestra rotunda, by percussion, and by the yielding of the lamina spiralis of the cochlea.

* See Müller's Physiology, pp. 1200 and 1206.

† Section ii. p. 1215, Müller's Physiology.

‡ Archiv. d'Anat. Physiol. Janvier, 1846, p. 16.

APPENDIX,

[CONTAINING some of the additions and corrections made by the author in the third edition of the first part of the original treatise ; the detail of experiments, &c. which appeared too long for insertion except in this form ; and some recently discovered facts having reference to the subjects discussed in the earlier part of the work.]

BOOK THE FIRST.

SECTION II.

Of the circulation.

CHAPTER II.

OF THE GENERAL PHENOMENA OF THE CIRCULATION.

Sounds of the heart, p. 176.

THE facts which the committee of the Medical Section of the British Association* determined by their experiments are the following:—Both sounds of the heart may still be heard (a stethoscope being applied to it) when the sternum and ribs are removed, and the heart is in contact with no part of the thoracic parietes. The two sounds having been heard in this way in a calf, two delicate needles of the proper curvature were thrust one into the aorta, the other into the pulmonary artery below the point of origin of the semilunar valves ; after being carried upwards for about half an inch, they were brought out again through the coats of the respective vessels ; so that between each needle and the parietes of the vessel one of the semilunar valves was included. Afterwards, on applying the stethoscope to the vessels, it was found that the second sound had ceased to be audible. These experiments tend to confirm Dr. Williams's opinion regarding the sounds of the heart. But even admitting that the first sound is due to the contraction of the ventricle,—is a muscular sound,—and the second produced by the reaction of the column of blood in the aorta and pulmonary artery upon the semilunar valves, spreading them out ; yet they must be rendered more perceptible by the heart striking against the thoracic parietes during the systole with its apex,—during the diastole with its anterior surface. [In their second Report † the committee state that further observations have verified the above conclusions.]

* Medical Gazette, Oct. 1836.

† Medical Gazette, Dec. 2, 1837.

CHAPTER IV.

OF THE INDIVIDUAL PARTS OF THE VASCULAR SYSTEM.

Structure of the capillaries, p. 217.

SCHWANN has recently ascertained, by means of the microscope, not merely that the capillaries have membranous parietes, but that this coat contains distinct circular fibres arranged as in arteries. He discovered them in the capillaries of the mesentery of the frog and brown or fire-toad (*rana bombina*). It is necessary to employ a high magnifying power and a rather feeble light; but they may be seen in the dead as well as in the living frog. (See also p. 377.)

BOOK THE SECOND.

SECTION I.

Of respiration.

CHAPTER I.

OF RESPIRATION IN GENERAL.

Poisonous gases, p. 293.

CARBONIC acid is one of the poisonous gases which can be taken into the lungs, for it does not excite coughing even when inspired in large quantity. It has a narcotic action on the system, producing asphyxia without exciting any symptoms of suffocation. Atmospheric air containing more than 10 per cent. of carbonic acid is quickly fatal.

SECTION II.

Of nutrition, growth, and reproduction.

CHAPTER I.

OF NUTRITION.

Chemical composition of the organised tissues, p. 367.

[Under this head the author in the third edition gives a new classification of the tissues, dividing them into]

1. *Tissues with an albuminous base.*—To which belong the brain and nerves, the muscles, glands, and mucous membranes.

These tissues yield no gelatin by boiling, which moreover produces little change in them; the cellular tissue which enters into their composition can alone be converted into gelatin. The different modifications of albuminous bodies are not at present well understood. We are acquainted with albumen only in the more restricted sense, and with fibrin; and the properties of these substances have been described in the chapter

on the chemical analysis of the blood. The ferrocyanide of potassium throws down a precipitate from the acetic acid solution of aluminous bodies, by which character these are distinguished from the following.

2. *Tissues which yield gelatin by boiling.*—To these belong,—1, the cellular tissue; 2, serous membranes; 3, tendinous tissue; 4, skin; 5, one kind of contractile tissue; 6, cartilage; 7, bone; and, 8, elastic tissue [including arterial tissue]. The animal matter which forms their basis either dissolves wholly into gelatin, or they continue to yield this substance for some time when submitted to long boiling. Some tissues, such as cellular and serous membranes, and bone, even after a few hours' boiling, yield a large quantity of gelatin; others, as cartilage and skin, yield but little of this substance even after fifteen or eighteen hours' boiling; while several days are required to extract it in small quantity from other textures, such as elastic tissues. The ferrocyanide of potassium produces no precipitate in the acid solution of these textures which yield gelatin.

The cellular tissue, the contractile tissue of the tunica dartos, the tissue of the serous membranes, the tendinous or fibrous tissue, and the tissue which forms the basis of the skin, yield the common gelatin or glue, *colla*, which is precipitated by tannin, chlorine, corrosive sublimate, and alcohol; but not by alum, acetic acid, acetate of lead, and sulphate of alumen. The precipitate thrown down by alcohol is again soluble in hot water.

The peculiar substance which I have described as the base of the permanent cartilages agrees in many points with the ordinary gelatin, but differs from it in the following particulars. It is precipitated by alum, sulphate of alumen, acetic acid, and acetate of lead. The precipitate produced by alum is redissolved on the addition of an excess of the reagent; that thrown down by acetic acid is not redissolved by the addition of more acid. Casein is likewise precipitated by the same reagents as the gelatin of cartilage or chondrin; but casein does not form a gelatinous mass when its solution cools, and, when thrown down by alum, it cannot be redissolved by an excess of that substance, while the precipitate which acetic acid produces is redissolved on the addition of more acid.

The cartilages are divisible into four classes:

a. *Cartilages containing peculiar corpuscles.*—The greater number of the permanent cartilages, and also the cartilage of bone before ossification, are composed of a semi-transparent, indistinctly fibrous tissue, containing in its substance numerous microscopic corpuscles generally of a flattened form, in the interior of which again there is often a nucleus or several granules. All the cartilages of this kind, namely, the costal cartilages, the majority of the cartilages of the larynx, those of the trachea, of the nose, and of the Eustachian tube, the articular cartilages, and the cartilage of bone before ossification, yield by boiling, according to my observation, the substance which I have named Chondrin, in place of the ordinary gelatin.

b. *Chondrinous fibro-cartilage.*—The cornea consists of three layers besides the delicate layer of epithelium which invests its free surface. The most superficial layer is rendered by hot water immediately of a snowy-white colour; the most internal lamina is the aqueous membrane, which is attached to the lamina fusca of the sclerotica; the middle layer, which constitutes the chief substance of the cornea, is formed of an interlacement of bundles of bright fibres without any intermixture of corpuscles. This is, according to my observation, reduced wholly to chondrin by boiling.

c. *Spongy cartilages;* their structure was discovered by Miescher. The cartilages of this kind are the yellowish cartilages of the external ear, the epiglottis, and the cartilages Santorinii et Wrisbergii of the larynx. They are yellow, and contain none of the corpuscles of Purkinje, but are throughout of a spongy texture, having large

cells. After being submitted to boiling during several days, they yield an extract in extremely small quantity, which does not form a jelly, but of which the chemical properties agree with those of chondrin; while the preceding cartilages dissolve within the space of fifteen or twenty hours into a chondrin which gelatinises on cooling.

d. Ligamentous cartilages. — These are interarticular cartilages, the intervertebral cartilages, the cartilages of symphyses. The substance which they yield by boiling is not chondrin, but gelatin entirely similar to that of tendons. They are constituted wholly of fibres, and contain none of the corpuscles of the first kind of cartilages. The tarsal cartilages of the eyelids, which are likewise fibrous, have not at present been examined with reference to their chemical composition.

The animal matter or cartilage of bone is composed of gelatin. It is remarkable that the cartilage of bone before ossification yields only chondrin when boiled, but after ossification affords the ordinary gelatin; such is the result of my observations. And even when the permanent cartilages, those of the larynx, for example, undergo ossification as the result of abnormal action, the ossified portion contains ordinary gelatin in place of chondrin. Bones which are affected with *mollities ossium* contain, by no means, a larger quantity of gelatin, but an extraordinary quantity of fatty matter.

Elastic tissue is yellow, and preserves its property of elasticity for any length of time in alcohol, and is not deprived of it even by several days' boiling. It yields very little gelatin, and that not until after several days' boiling. The gelatin has peculiar characters; it cannot, therefore, be derived from the cellular membrane which is inclosed in the elastic tissue. It bears a great resemblance to "chondrin," but yet is not identical with it. The solution of the gelatin of elastic tissue is rendered very turbid by acetate of lead and acetic acid, and is precipitated by common alum and by sulphate of alumen; but the sulphate of the peroxide of iron renders it opaline merely, without throwing down any precipitate.

CHAPTER II.

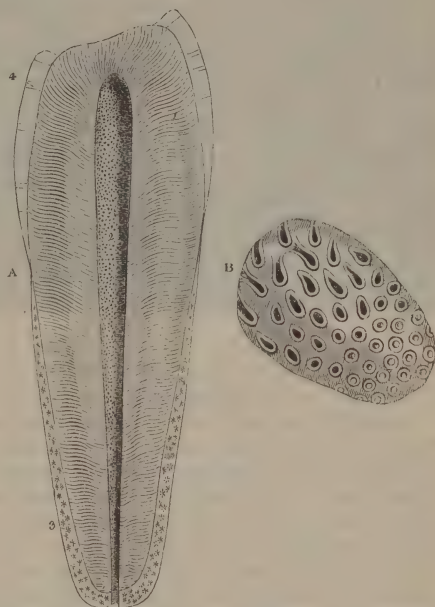
OF GROWTH.

Structure and growth of the teeth, p 394.

[Important additions have been made to our knowledge of the structure of the teeth by the labours of Professor Retzius of Stockholm.† Retzius discovered, nearly at the same time with Purkinje, that the teeth of man and many animals consist of three distinct substances:—

1, the enamel; 2, a tubular substance (the ivory) composing the greater part of the tooth; and 3, a cortical substance surrounding the fangs, which contains the peculiar osseous corpuscles (fig. I, A.) He has, however, since ascertained not merely that the fibres of the ivory are tubular, a fact known, it appears, to Leeuwenhoeck;‡ but also that these tubuli in their course from the cavity of the pulp to the surface of the teeth give off numerous branches, and terminate in fine anastomosing fibres which communicate with minute cells or corpuscles, like those of the cortical layer of the tooth and bone.

Fig. I.*



The following is the description given by Retzius of the tubes of the ivory in the human tooth. The tubes have a general radiate disposition around the cavity of the pulp, being directed perpendicularly to the surface of the tooth (fig. I, A, 1). Their

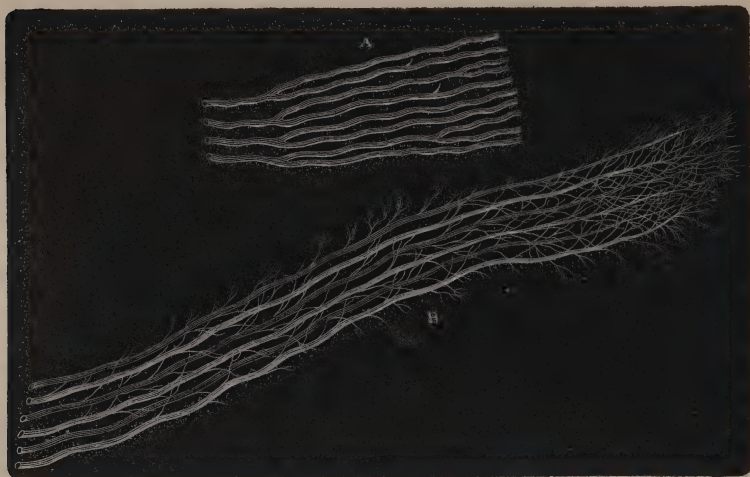
* [Fig. I.—A. Section of a human molaris divided in the direction of the axis of its pulp cavity, magnified four diameters. 1. The ivory, showing the direction and larger curves of the dental tubes. 2. The cavity of the pulp, showing the openings of the dental tubes. 3. The cortical substance, surrounding the fang as high up as the border of the enamel. 4. The enamel.—B. A small portion of a section of a similar tooth made perpendicular to the course of the dental tubes, showing the openings of these tubes and their parietes distinct from the uniting substance. The tubes to the left hand cut obliquely. This, and all the succeeding figures illustrating the structure of the teeth, are copied from Retzius.]

† [Müller's Archiv. 1837, p. 486.]

‡ [Philos. Transact. 1678, and Contin. Epistol. Ludg. Bat. 1780.]

course is for the most part waving, each tube having three curves like the Greek letter (ξ). Besides these primary curves, the tubes, when examined with a higher magnifying power, are seen to present smaller secondary undulations (fig. II, A and B),

Fig. II.*



which are less perceptible in the deciduous than in the permanent teeth, and less marked at the external extremity of the tubes than in the middle of their course. The undulations are nearly parallel in the different tubes, and thus give rise to the appearance of concentric lines around the cavity of the pulp in a section of the ivory. The diameter of the tubes remains the same (namely, $\frac{1}{4\frac{1}{17}}$ of a French line, or about $\frac{1}{8\frac{1}{5}}$ of an English line,) from their commencement at the cavity of the pulp to the middle of the outer third of their course; it then diminishes rapidly, until the terminal branches cease to be visible, or terminate in small irregularly round cells. With a magnifying power of 300 to 500 diameters, it can be seen that the tubes are not simple, but branch by a dichotomous division (fig. II, A), and in their whole extent give off numerous side twigs, which again subdivide and occupy the spaces between the principal tubes (fig. II, B). These minute lateral branches are seen most readily in the deciduous teeth; those from different tubes appeared to Retzius not to anastomose, except, perhaps, by their finest extremities. The tubes have a more regular arrangement, their lateral branches are smaller, and the cells more minute and difficult to discover, in the human teeth than in those of any other animals. In many mammalia, as the horse, the cells or corpuscles are large and distinct (fig. III). The minute structure of the teeth is examined in sections made by means of the saw, and reduced to the necessary degree of thinness by files. Such laminae, when as thin as writing paper, are not sufficiently transparent until moistened with water, or impregnated with turpentine, varnish, or oil; but, when completely permeated with these liquids, they become too transparent, and the ramifications of the tubes, particularly the more minute twigs, become invisible; the

* [Fig. II.—A. Innermost portion of the dental tubes from the incisor of a child two years of age, showing their dichotomous division. — B. External portion of the tubes, showing their ramifications.]

branches are seen best when the newly made section is first laid in either of the fluids above mentioned.

Fig. III.*



When the wall of the cavity of the pulp of a tooth is regarded with a sufficiently high magnifying power, it is seen to be perforated by numerous small orifices, separated by narrow interspaces (fig. I, A, 1) ; these are the openings of the dental tubes. In sections also made at right angles to the course of the tubes their lumen can be seen, and they then appear as bright rings surrounding a spot, which according to the variation of the light is dark or light, or in part dark and in part light (fig. I, B). Some of the tubes are seen to be cut obliquely. The rings have a different aspect from the substance in which they are imbedded, and have sometimes a yellowish colour ; hence, as well as from the observations of Professor Müller (see page 394), it is evident that the tubes have special parietes, and are not mere excavations in the substance of the ivory. Professor Retzius confirms the observation of Professor Müller, that the tubes contain an inorganic earthy matter in granular masses, which disappears under the action of dilute muriatic acid. The cells, and the small tubes which radiate from them, also contain earthy matter, as in bone (see page 380). They are naturally white and opaque ; but, after maceration in dilute muriatic acid, become colourless and transparent.

Examining the ivory in different mammalia, reptiles, and fishes, Retzius met with many varieties of structure, the most important of which are those which show the great resemblance of ivory to bone. The cells or corpuscles are in many mammalia in greatest abundance at the superficies of the ivory ; but in others they, together with the fine tubes which issue from them or terminate in them, and which are continuous with the branches of the larger dental tubes, occupy in greater part all the interspaces between the latter. These cells of the ivory contain calcareous matter, and are evidently analogous to the corpuscles discovered by Purkinje in bone, which also have fine anastomosing tubes radiating from them (see plate 1, fig. 13). The part of the ivory formed after the teeth have emerged from the gum, namely, the extremity of the fang, and that part which fills up the cavity of the pulp, has less regularity of structure than the ivory previously formed ; the tubes are less parallel, the cells larger, and the anastomoses of the small tubes terminating in these more distinct ; all which circumstances give this imperfectly formed ivory a great resemblance to true bone. But the ivory in the teeth of some animals presents characters which assimilate

* [Fig. III.—External portion of the dental tubes from the incisor of a full-grown horse, showing the numerous cells in which the dental tubes terminate]

late it still more remarkably to the structure of bone. In the teeth of man and most mammalia, the ivory is formed regularly in successive layers on the surfaces of the pulp, which in the body of the tooth undergoes no other change than gradual diminution in size, and periodic movements which give rise to the undulations of the dental tubes. In other animals, however, as the sloth (*Bradypus*), walrus (*Trichechus*), pike (*Esox*), ling (*Gadus molva*), and wolf-fish (*Anarrhichas lupus*), the pulp, after forming the most external layer of ivory, consisting of closely set dental tubes perpendicular to the surface, divides into a number of processes, similar to, but more numerous than, those which form the fangs of the human molares; and around each of these processes or branches of the pulp ivory is formed in layers. In many instances, as in the saw-fish (*Pristis*), ling, and wolf-fish, the numerous divisions of the pulp anastomose with each other like the medullary canals of bone. This form of ivory presents in many animals, particularly in the walrus, the most striking resemblance to bone; the divisions of the pulp are seen surrounded with concentric laminae, which, like the layers of bone surrounding the medullary canals, contain rings of cells or corpuscles; and these laminae, again, are traversed by fine radiating tubes analogous to the radiating striæ in bone, which were supposed by Deutsch to be tubes (see page 378).

Retzius noticed, that in *Gadus molva* and *Esox lucius* there was a gradual transition of the bone, to which the teeth in these as in many other fishes are firmly anchylosed, into the substance of the ivory of the tooth; and he observed that in the *Gadus* and *Squalus Cornubicus* the small remaining pulp cavity of the tooth was continuous with the medullary canals of the bone, while, on the other hand, the trunks of the large dental tubes which issued from the cavity of the pulp contained a red matter similar to the pulp. Mr. Owen,* who has confirmed the researches of Retzius, and has extended his observations particularly among the fossil teeth of different animals, points out in them also the great resemblance of the less perfectly organised ivory of the fish's tooth to bone, the ramification and anastomoses of the divided pulp, the concentric laminae surrounding the pulp canals, and the smaller radiating tubes traversing these laminae; in the tooth of the extinct *Acrodus*, as well as the existing *Lamna*, he found that the pulp canals communicate directly with the large cells of the bone with which they are anchylosed.

Retzius shows that, in the sloth and in the pike, the dense layer on the surface of the tooth, which to the naked eye looks like enamel, is really formed of delicate and closely set tubes perpendicular to the surface, while the mass of ivory within this has a coarser structure. Mr. Owen finds the same structure in the teeth of the extinct *Megatherium*, in which, as in all existing *Edentata*, the enamel is absent. The external enamel-like layer in the teeth of many existing and extinct fishes also has been detected by Mr. Owen to be a fine layer of ivory, like the analogous part described by Retzius in the teeth of the sloth and pike.

The *cortical substance* or *cement* (fig. I, A, 3), which exists in very various quantity in most mammalia, and some reptiles and fishes, is in all cases characterised by the presence of the osseous cells or corpuscles, and the anastomosing calcigerous tubuli. But in many animals it is traversed by larger canals which communicate with the cavity of the pulp; to which they probably transmit blood-vessels. It sometimes also contains large canals, which open upon the external surface. Both Retzius and Mr. Owen have seen direct communications between the fine branches of the tubes of the ivory and the tubes and cells of the cortical substance.

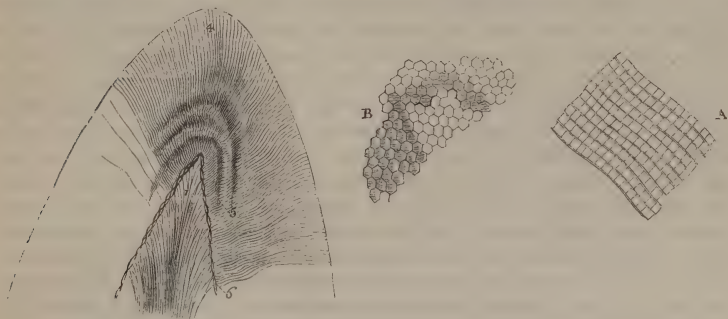
The *office of the system of dental tubes and cells* is supposed by Retzius to be the

* [See Report of the eighth meeting of the British Association.—Athenæum, September 1, 1838.]

distribution through the tooth of a nutritive or preservative fluid secreted by the surface of the pulp. The solid material of the tooth undergoes probably no change; but still M. Retzius supposes that the ivory and cortical substance may be the seat of a vital process, consisting in the interchange of material in the fluids of the tooth; this vital process being, he conceives, necessary to maintain in them that property by which they are enabled to suffer constant pressure without injury or wasting. The teeth would, therefore, appear to be not mere extravascular bodies foreign, as it were, to the organism, though formed by it; but structures belonging to the osseous tissue, though characterised by a peculiar arrangement of their parts, and a degree of organisation adapted to the purpose for which they are destined in the œconomy.

Fig. IV.*

Fig. V.†



The *fibres of the enamel* (fig. IV, 4) are described by Professor Retzius to be six-sided prisms, about $\frac{1}{500}$ of a French line, or $\frac{1}{461}$ of an English line, in diameter. The surface of the fibres is marked with transverse striæ (fig. V, A), which Professor Retzius is inclined to ascribe to a thin organic sheath enclosing the inorganic prismatic fibres. Their hexagonal form is beautifully seen on the surface of the tooth by the aid of a magnifying power of 300 diameters (fig. V, B). In parts where the tooth had not been worn down, the external extremity of each fibre appeared to be rounded. The inner extremity rests on a delicate membrane interposed between the enamel and the ivory. This membrane was known to Berzelius. The surface of the ivory presents a number of small depressions, which receive the ends of the fibres of enamel (fig. IV, 6). In their course from the surface of the ivory to the external surface of the tooth, the fibres of the enamel follow a more direct or oblique line, according as they are nearer to the fang or to the crown of the tooth. In some teeth, and in some parts of the teeth particularly, they are variously curved, sometimes presenting parallel wavings (fig. IV, 5). In the crown of the human teeth, and in some parts of the teeth of mammalia, there are fibres near the superficies of the enamel, which are interposed as wedges between the other fibres, and do not reach the

* [Fig. IV.—Upper portion of a longitudinal section of an incompletely formed incisor taken from the follicle.—1. The ivory and dental tubes. 4. The enamel. 5. Parallel curves of the enamel, giving rise to the appearance of concentric lines when a lower magnifying power is used. 6. Small depressions and points on the surface of the ivory, upon which the fibres of the enamel rest.]

† [Fig. V.—A. Fibres of the enamel seen laterally with a magnifying power of 350 diameters, showing the transverse striæ upon them.—B. A portion of the surface of the enamel, showing the hexagonal ends of the fibres. A fissure is seen following the line of union of the fibres.]

surface of the ivory. The yet soft and pulp-like enamel on the last molar tooth of a calf was found by Professor Müller to consist wholly of acicular fibres acuminate at both extremities.

The *development of the teeth* has been recently investigated by Mr. Goodsir,* who has succeeded in observing the process at an earlier stage than has hitherto been done, namely, before the formation of the dental sacs. Dentition commences, he says, by the formation of "the primitive dental groove, on the floor of which the rudiments of the pulps of the milk-teeth appear as globular or conical papillæ; septa afterwards pass from the outer to the inner side of the groove, between the papillæ, and thus each of the latter becomes situated in an open-mouthed follicle, which is the primitive condition of the future sac." The rudiments of the ten anterior permanent teeth appear as little depressions in the groove, internal to the mouths of the follicles of the milk-teeth. The papillæ of the milk-teeth now begin to be moulded into the form of pulps, and at the same time the mouths of the follicles become closed "by two or more laminae, which agree in number, shape, and position with the cutting edges and tubercles of the future teeth." The opposite lips and walls of the groove above the follicles now unite, except in the situations of the ten depressions for the permanent teeth, and for a small extent posteriorly on each side, where a portion of the groove remains in its primitive condition. Here the papillæ and follicle of the first large molar tooth appear, and, after the follicle closes over, the lips of the groove above it unite, but not the walls, so that a cavity is left in which the sacs of the two posterior permanent molars are formed. The first large grinder may, therefore, be considered a milk-tooth as to its mode of development. Mr. Goodsir concludes from his researches that the human teeth originate from mucous membrane, that the permanent teeth have no connection with the deciduous set, and that the sacs and pulps must be referred to the class of organs denominated bulbs.†

CHAPTER III.

OF REPRODUCTION.

Formation of Callus, p. 414.

THE whole process of the formation of callus has been recently investigated by M. Miescher,‡ and with considerable success. The following are the results at which he arrived.

When a bone is fractured, the surrounding soft parts—the periosteum, cellular tissue, and muscles,—are at first the principal seat of the inflammation; they swell, become thickened and glued together, forming a dense capsule around the fracture. On the inner surface of this capsule a semifluid exudation, which by degrees becomes solid and organised, is formed as the product of the inflammation. A similar substance is effused by the medullary tissue of the broken bones; this unites, and forms one mass with the exudation within the capsule; and the whole constitutes the "*substantia intermedia*" which envelopes the ends of the bone. This "*substantia intermedia*"

* Report of the eighth meeting of the British Association for the Advancement of Science.—Athenæum, September 15, 1838.

† [Since the above was printed, it has been pointed out to the translator, that Mr. Goodsir has been anticipated in his interesting discovery by Arnold, who, according to Valentin, (*Entwickelungs geschichte des Menschen*, p. 482,) has observed that the dental sacculi are formed by diverticula of the mucous membrane of the mouth being received into the groove of the jaws. The reference given for Arnold's observations is: the *Salzb. Mediz. Chir. Zeit.* 1831. s. 236.]

‡ De inflammatione Ossium eorumque Anatom. generali. Berol. 1836.

acquires a fibrous texture, and fills all the space between the bones; while the muscles, cellular tissue, and periosteum return to their former normal condition. The inflammation does not affect the bone so soon as it does the soft parts; it commences in it at some little distance from the fractured extremities, namely, at the part where the bone is still invested by periosteum, and at the same point in the interior. The bone likewise pours out a gelatinous exudation, in which vessels become developed, and which continues to grow; while, on the side by which it is connected with the bone, it becomes converted into cartilage and bone. This new mass, the proper callus, also occupies to a greater or less extent the medullary cavity. On the exterior its formation is continued towards the fractured extremities, till the exudations of the two portions of bone meet and unite. Thus is formed the primitive callus.

In the mean time the surface of the bone unites with the capsule formed by the soft parts and the primitive callus; the margins of the fracture again unite with the "substantia intermedia." A callus too is formed, and develops itself at the expense of the now ligamentous "substantia intermedia." Periosteum is formed anew on the external uneven surface of the callus.

The first appearance of the primitive callus is at that part of the bone where the periosteum is still in connection with the bone; it is effused as a half-fluid matter between the bone and periosteum; vessels appear in it as early as the fourth day. The callus, therefore, according to Miescher's investigations, always arises from the bone itself. When, in sections of united fractures, nuclei of bone were seen in the callus apparently unconnected with that part of the bone at which the production of callus commences, it was always found, on closer examination, that these nuclei were really connected with that part of the bone.

The further changes which the callus undergoes after the ends of the bone have united, consists in the restoration of the medullary cavity in its substance, and in the change of its form. The texture of the callus undergoes the same changes as the cartilage of bone in ossification. While it is cartilaginous, it contains the peculiar corpuscles of cartilage; when it ossifies, it assumes the cellular texture of bone.

Reproduction of bone subsequent to Necrosis, p. 427.

Miescher has shown Scarpa's opinion, that the old bone undergoes an expansion, to be not exactly correct. The enlargement of the external laminae of the bone which retain their life in the internal necrosis, is effected by exudation.

BOOK THE FOURTH.

SECTION III.

Of Voice and Speech.

CHAPTER I.

OF THE GENERAL CONDITIONS FOR THE PRODUCTION OF SOUND.

Theory of the sounds produced by tongues.—See page 985.

THE observation that sounds can be produced by the mere impulse of fluids upon each other, as exemplified in the Siren, or by a quick succession of impulses of a solid body, as when a piece of wood is struck by the teeth of wheels, has inclined many persons to the belief that sounds produced by vibrating tongues result from the impulses communicated to the air beyond by the current of air interrupted in its passage through the opening of the reed by each vibration of the tongue. This view is apparently con-

firmed by the circumstance that the sounds produced by striking tongues without the aid of a current of air are very feeble; but, nevertheless, the theory is by no means proved, and there are several facts directly opposed to it. The elucidation of this question is of great importance with reference to the physiology of voice; for on it depends whether we should regard the vocal cords or the air as the primary source of the voice.

M. W. Weber* found that a metal plate fixed in its frame might be thrown into strong vibrations by a stroke of a violin bow; but that a full loud tone, like that produced by a current of air passing through the frame, could not be thus obtained. The tongue of a jew's harp, however, I find, yields, when held between the teeth, the same sound, whether it be struck or made to vibrate by drawing air into the mouth. [This is most probably owing to the air within the mouth in each case reciprocating the sonorous vibrations of the tongue of the jew's-harp, and thus rendering them louder, on the principle pointed out by Mr. Wheatstone.—(See page 1021, note †)]. The above fact, adduced by M. Weber, does not appear to me to be a decisive proof of the theory in question; and in the case of the membranous tongues, at all events, the interruption of the current of air, and the impulses thus produced, seem to me to have only a subordinate influence in the production of the sound, rendering it stronger and fuller rather than generating it.

The following are my reasons for thinking it improbable that the sounds of vibrating membranous tongues are produced by the impulses of the air.

1. That explanation of the sounds is unnecessary, since the vibrations of the tongues themselves are alone sufficient to cause those sounds. The difference in strength of the sounds produced by striking membranous tongues, and of those caused by the action of a current of air, is sufficiently explicable on the supposition that the momentary stroke is inadequate to maintain the vibration. There is certainly also a difference in timbre between the two sounds; but the same is observed in the case of other instruments where the impulse is not continued; the sound of a stretched string, for example, has a different tone when produced by a stroke of the fingers merely, from that which characterises it when the string is kept in vibration by the continued action of the violin bow. Some membranes, indeed, yield no sound when struck, though they give out loud tones when thrown into vibration by a current of air; such is the case, namely, with the lips and sphincter ani. But a certain number of vibrations within a given time are necessary for the production of any sound, and the fact just stated merely shows that the regular succession of vibrations can be produced in such lax membranes only when they are at the same time kept somewhat extended by a current of air.

2. The sounds which I have found to be produced by blowing through a small tube upon a delicate metallic, or, still better, a membranous tongue, destitute of frame, cannot be accounted for on the principle of the interruption of the current of air alone; and, nevertheless, they have exactly the same timbre as those emitted by metallic or membranous tongues fixed in a frame. It might, indeed, be urged, that even here the current of air is in some measure interrupted by the returning vibration of the tongue. But the current of air can in this case scarcely be said to be interrupted, since the air escapes in other directions in proportion as the returning tongue impedes its direct progress. The current of air must rather be regarded as acting, like the violin bow on a string, as a continuous excitant of the vibrations.

3. Moreover, it is not necessary that the opening in the frame should be periodically closed by the vibrating tongue, at least not in the case of the membranous tongues. When the cleft between them is a line in breadth, membranous tongues often yield clear tones of the ordinary timbre.

* Poggendorf's Annal. t. xvi. p. 421.

4. If the sounds of vibrating tongues are really due to the periodic interruption of the current of air, they ought to rise in pitch in direct ratio with the frequency of the interruptions ; which is by no means proved. When a tongue is so placed in its frame, that in vibrating it passes quite through the opening, it must interrupt the current of air twice in each vibration, namely, when forced out of the frame and in its return ; when, on the contrary, a tongue does not pass entirely through the opening, but only returns to a level with it, and is then forced out again, it only interrupts the current of air once : in the former case, therefore, the sound ought, *cæteris paribus*, to be an octave higher, which is not the case. To this it might be answered, that when the tongue does not pass entirely through the opening, it merely performs half-arcs of vibration, being prevented from completing them either by the frame itself or by the current of air, and that consequently it would vibrate twice as fast as when it traverses the whole arc of vibration, passing and repassing the opening in the frame ; but on investigating the mode of action of membranous tongues, difficulties again present themselves. A membranous tongue stretched across the lower extremity of a tube, and having opposed to it a solid plate of pasteboard or wood, yields the same tone, whether the solid plate be on the same level with it, or be pressed inwards towards the cavity of the tube. In either case the tongue performs entire arcs of vibration. But if the solid plate be so placed as to lie on a level in front of the tongue, the sound produced by blowing through the tube is, I find, much lower in pitch, namely, as much as the interval from C to the lower F. The arcs of vibration would, nevertheless, here be the same. The difference depends on the different manner in which the current of air acts on the tongue, and on the different degree of resistance which the continuous current of air offers to the return of the vibrating tongue.

These reasons render it probable that the primary source of the sound produced by tongues is not the impulses of the interrupted current of air, but the vibrations of the tongue itself, and that the impulses imparted to the air merely increase the strength of the sound. In studying the vibrations of bodies rendered elastic by tension, the strings of stringed instruments and similar bodies have been kept too exclusively in view ; such bodies when much shortened, and at the same time relaxed, lose almost all capability of yielding sonorous vibrations ; but other substances, as caoutchouc and elastic animal tissue in the moist state, when much relaxed, have still sufficient elasticity to vibrate with regularity, and yield sounds.

The laws regulating the variation of the notes produced by metallic tongues are generally the same as those for metallic rods, and the membranous tongues in the variation of their notes follow generally the same laws as the stretched strings ; but still the metallic and membranous tongues differ in their action from the rods and strings in the circumstance of the pitch of their notes being influenced by the intensity of the action of the cause exciting their vibrations, namely, the air (see pages 989 and 991). This difference is not, however, absolute ; for a string yields a somewhat lower note when struck with the finger more strongly ; and Duhamel * has shown that deeper tones may be obtained by carrying the bow across the string, so as to modify the friction and its rapidity.† This is, however, a contrary effect to that of increased force of the blast on membranous tongues, the notes of which are raised several semitones by blowing with increased force. By blowing with gradually increased force into a small closed pipe two inches in length also, I can produce a gradual sharpening of the sounds from C to F without intervals ; a result very different from that of blowing with increased force into longer pipes, where notes with determinate intervals are produced from the development of nodal points. The various modifications produced in the pitch of the notes yielded by a vibrating tongue by varying its relation to the frame,

* L'Institut, No. 186.

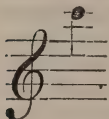
† Compare Pelisow, in Poggendorf's Ann. xix. p. 251.

by directing a current of air upon it when destitute of frame, by altering the form of the mouth in blowing, &c. are, without doubt, owing to the manner in which the air is made to act upon the tongue.

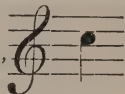
Influence of a pipe conjoined with vibrating membranous tongues on the pitch of the sounds given out by the latter, p. 994.

In my first experiments to ascertain this point, I combined with the pipe of a clarionet reeds constructed with a single tongue of caoutchouc and of various pitch. The result was, that the fundamental note of the tongue was lowered.

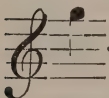
I subsequently obtained from an organ-builder five cylindrical pipes of pasteboard one inch in diameter, and of different length, which could be fitted together. The first, with which the reed was connected, served as the "foot" for the others; and it was of such dimensions that the fundamental note of its column of air was C,



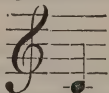
A second pipe was of such length that, combined with the first piece or foot, it gave as the fundamental note the lower octave of C,



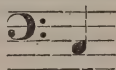
The third, combined with the foot-piece, gave out the "fifth" of the last C, namely G,



The fourth pipe with the foot-piece had, as fundamental note, the second lower octave of the first C, namely



The fifth was of such length that, with the preceding pipe and the foot-pipe, it yielded the third octave below the first C, namely



These were the notes which the pipes were capable of yielding without the reed. I constructed several reeds of different kinds. Three were of the forms described at page 989: in these the direction of the cleft through which the air passed was perpendicular to the axis of the reed or mouth-piece. In a fourth, two membranous tongues were stretched over a lateral opening in a reed; so that the cleft between them was parallel to the axis of the reed.

The results of the combination of these reeds with the pipes of different length were very much at variance with each other. Generally the fundamental note of the reed was lowered, sometimes less than a semitone, sometimes from a semitone to an entire tone. No definite law seemed to prevail. When the next pipe to the foot-pipe was added, the note was sometimes lowered one or more semitones, or it was raised to its original pitch; this again seemed to be regulated by no constant law. On account of the difficulty of arriving at a satisfactory result in these experiments, I was careful to adopt as data those sounds only which were produced by the weakest blast. In some instances, even with the addition of the second pipe, by which the fundamental note of the column of air was lowered an octave, the pitch of the sound yielded by the reed was not perceptibly depressed. In this case the addition of the third pipe sometimes lowered the note a semitone or a tone; in other instances, the sound emitted remained at the same pitch even when the second, third, and other pipes were added, as when merely the first pipe was combined with the reed. When the pitch was lowered by the second pipe, it was generally raised, when another pipe was added, to such an extent that the sound produced was identical with or near to the fundamental note of the reed combined with the foot-pipe alone; and then the pitch was not affected by the

addition of the other pipes, or was merely lowered to a very slight extent by the last pipe. As the basis of comparison between the sounds of the reed alone, and those which the pipes alone were capable of yielding, a special flute-pipe with the same fun-

damental note as that of the foot-piece with the next pipe, namely C,

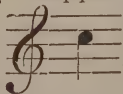


was used. The note yielded by the reed alone, and those produced by the combination of the reed with the different pipes, were always determined by means of a well-tuned pianoforte.

The results of experiments frequently repeated with this apparatus, reeds of various pitch being used, were remarkably at variance with each other. The causes of this discrepancy in the results were the different relation which the fundamental note of the reed bore to that of the pipe, and the different degrees of force with which it was necessary to blow to elicit the notes, and which immediately modified their pitch. Thus much, however, was proved with certainty; that a short tube, of which the fundamental note was much higher than that of the reed separately, when combined with it, the prefixed tube or "porte-vent" being short, does not raise the note of the reed nearer to its own pitch, but usually lowers it somewhat; and that an increase of the length of the pipe when the note of the reed is already lowered, at length restores it nearly to its original pitch. In these experiments the air was blown upon the membranous tongue from the mouth, in which the mouth-piece was held; the air then necessarily passed through the pipes after acting on the tongue; it is very interesting that when a current of air is directed upon the surface of the membranous tongue from a small tube, so that no current of air traverses the lower pipes, these pipes still had some influence on the note yielded by the tongue.

My experiments thus far afforded me only an imperfect idea of the modification which the sound of a membranous tongue experiences from its combination with a pipe. Pipes of certain dimensions may have little effect on the sounds; while pipes of different proportionate length might have a greater influence. This is indeed a principal reason wherefore, in the experiments to which I have alluded above, the pipes had sometimes only a slight influence on the note given out by the reed; while, when the reed had a different pitch, they produced great changes in it. With the view of attaining to the knowledge of the law regulating these varieties, I have employed tubes one inch in diameter, and so constructed that they could, by the addition of successive small portions, be lengthened from an inconsiderable length to that of four feet; so that the influence of the pipe on the pitch of the reed could be ascertained at all lengths. From the former experiments, in which I used pipes of the same length with tongues of different pitch, it resulted that the influence of the pipe was not uniformly proportionate to its length. The present series of experiments (of which some examples follow) proved still more clearly that the modifications of the sound depend on the relation existing between the fundamental note of the tongue and that of the pipe. [The results are stated more fully at page 992.] The pipes I used being one inch in

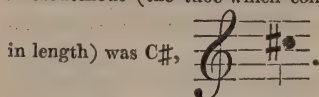
diameter, their fundamental note would be C



, when their length is

eleven inches four lines (French measure). The fundamental notes of the pipes of different length in the following experiments may therefore be easily calculated.

Experiment I.—The fundamental note of the reed formed with a one-lipped tongue of caoutchouc (the tube which conveyed the wind to the tongue being three inches

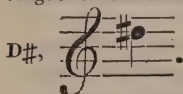


Length of pipe. Note produced.

Remarks.

0 inches.	C $\sharp$	
6	C	The note becomes lower.
6 „ 9 lines.	B	
7 „ 6 „	A $\sharp$	
9	A	
9 „ 6 „	A—C $\sharp$	{ Sudden rise from A to C $\sharp$, which is the note produced until the pipe attains nearly the length of 18 inches.
18	C	
20	C $\sharp$	Flattening of the note.
22 „ 6 „	A—C $\sharp$	{ Sudden rise ; C $\sharp$ constant until the pipe is nearly 30 inches in length.
30	C	
31	B—C $\sharp$	Fall of the note.
36	C $\sharp$	Sudden rise.
40	C	Fall of the note.
45	B—C $\sharp$	Sudden rise.
48	C $\sharp$	

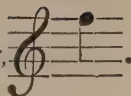
Experiment II.—The fundamental note of the reed constructed with a one-lipped tongue of caoutchouc, sounded directly by the mouth without prefixed tube, was



Length of pipe. Note produced.

Remarks.

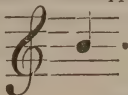
0 inches.	D $\sharp$	
3	D	Lower notes are produced.
4 „ 6 lines.	C $\sharp$	
5	C	
6 „ 6 „	B	
7	A $\sharp$	
8	A	
9 „ 6 „	G $\sharp$	
10	G $\sharp$ —C $\sharp$	Sudden rise.
11	C $\sharp$	Lower notes produced.
13	C	
17 „ 6 „	B	
20 „ 6 „	A $\sharp$	
22	A	
23 „ 6 „	G $\sharp$	
26 „ 6 „	G $\sharp$ —B	Successively—the sound rising.
31	A $\sharp$	
35	A	The sound falls in pitch.
39	G $\sharp$	
41	G $\sharp$ —B	In succession.
45	A $\sharp$	The sound falls in pitch.

Experiment III.—One-lipped tongue without prefixed tube.*Length of pipe. Note produced.**Remarks.*

3 inches. 6 lines.	F	The F on the upper line of the treble clef,
4 " "	E	The sound falls.
4 " 6 "	D#	
5 "	D	
6 "	C#	
6 " 3 "	C	
7 " 6 "	B	
8 "	A#	
8 " 6 "	A	
9 "	G#	
9 " 6 "	G	
10 "	F#	The F of the lower octave.
11 " 3 "	F	
12 "	E	
12 " 6 "	D#	
14 "	D	
17 " 6 "	D#	
19 "	D# & C	{ In succession. — Rise to the same note as when the length of the pipe was 6 inches 8 lines.
20 " 3 "	B	The sound falls in pitch.
21 "	A#	
22 " 6 "	A	
24 "	G#	
25 "	G	
29 " 9 "	F#	The F of the lower octave.
33 "	F	
34 " 3 "	E	
35 " 6 "	D#	
38 " 6 "	D# & C	In succession. — Rise.
40 "	D#	The sound falls in pitch.
42 "	D	
42 " 9 "	C#	
43 " 4 "	C	
44 " 4 "	B	
44 " 6 "	A#	
45 "	A	
46 "	G#	

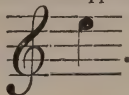
Experiment IV.—Fundamental note of a one-lipped tongue, (sounded directly by

the mouth without prefixed tube,) B,

*Length of pipe. Note produced.**Remarks.*

0 inches.	B	
1 " 2 lines.	A#	Lower notes produced.
2 "	A	
3 "	G#	
7 " 6 "	G	
9 "	F#	
10 "	F	
13 "	E	
17 "	D#	
22 " 4 "	A# +	Sudden rise.
23 "	G	Lower note again produced.
25 " 6 "	F#	
27 " 6 "	F	
32 "	E	
39 " 6 "	D#	
40 "	G	Sudden rise.
42 " 3 "	F#	Lower notes again produced.
45 "	F	

Experiment V.—Fundamental note of the one-lipped caoutchouc tongue sounded from the mouth without prefixed tube, E,



Length of pipe. Note produced.

Remarks.

3 inches.		D#	Lower notes produced.
3	9 lines.	D	
4	9	C#	
5	6	C	
6	2	B	
7	4	A#	
10		A	
13	6	F	Sudden rise.
15		D	Lower notes again produced.
15	8	C#	
17	6	C	
20		B	
24		A	
28		D#	Sudden rise.
29	6	D	Fall of the notes.
30		C	
30	6	B	
34		A#	
35		A	
41	6	D#—F	Sudden rise.
42		C	
43		B	

Experiment VI.—The fundamental note of a one-lipped caoutchouc tongue with a

pipe of 5 inches was G,



The border of the tongue rests in some degree

on the plate of wood or the frame. Lower notes are produced as the pipe is lengthened until it is 21 inches long, when there is a sudden rise to the original pitch; the pipe being elongated still further, lower notes are again produced until the length of the pipe is 42 inches, when there is again a rise of the notes to the original pitch; after which point elongation of the pipe produces a renewed fall of the notes.

These experiments were frequently repeated, and constantly afforded similar results.

CHAPTER II.

OF THE ORGAN OF VOICE IN MAN AND ANIMALS.

Effect of varying the tension of the vocal cords on the notes they yield, page 1011.

FREQUENTLY a larynx is found quite incapable of use in these experiments, on account of its tendency to the production of shrieking harmonic tones by the opposite points of the lips of the glottis coming into contact with each other in their vibration. Generally the male larynx is preferable by reason of the greater length of its vocal cords. The experiments must, however, be frequently repeated before a case will occur where the shrieking harmonic notes can be avoided. I give here the results of several experiments, in which the separated organs of voice acted most favourably.

A difficulty in these experiments lies in the circumstance that the vocal ligaments cannot be extended in the direction of their length by means of determinate weights, without other parts offering some resistance to the extending force. When the extension is exerted from the thyroid cartilage, the elastic tissue between this cartilage and the cricoid will diminish the effect of the tension; this elastic membrane may be divided, and still the articulation between the two cartilages will exert a similar influence; this articulate connection also may be divided, and even then the sounds produced by great degrees of tension will be lower in pitch than they ought to be according to the law of strings and membranous tongues, if the harmonic tones be not produced. In the following experiments the extension was made in somewhat different directions; in some in the exact direction of the vocal cords, in others in a direction a little behind or in front of this line, with the view of ascertaining the extent to which the results might thus be varied. The fundamental note was, of course, somewhat changed according to the direction in which the extending force acted.

Another difficulty arises from the impossibility of always blowing with exactly the same degree of force; the sounds produced being higher in pitch in proportion to the strength of the blast. It is best, however, to take as the basis of comparison such sounds only as are produced by the most feeble blast, or the fundamental notes of the vocal cords. The mode in which the larynx was fixed, and the weights attached to it, is described at page 1008.

Degree of tension as measured by weights.			4 Loth.	16 Loth.	64 Loth.
Notes produced.	Experiment	1	C ¹	A ¹	G ² #
	"	2	C ¹ #	B ¹	A ² #—A ²
	"	3	G ¹ #	C ² #	C ³
	"	4	A ¹	D ²	C ³
	"	5	A#	F ¹ #	G ²
	"	6	A#	G ¹ #	G ²
	"	7	D ¹	C ³	A ²
	"	8	D ¹ #	B ¹	A ²
	"	9	G	G ¹	G ² (Both octaves imperfect).

[The notes of the different octaves from (C to C) are distinguished in the above

table by cyphers. The C¹ is . The notes of the octave below this C

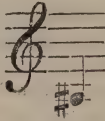
have no cypher.]

The notes were in each experiment ascertained by means of a well-tuned piano-forte.

Compass of the notes produced by various degrees of tension of the vocal cords, p. 1012.

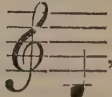
The mode of performing the experiment when the extension is made by depressing the thyroid cartilage in the manner of a lever is as follows:—The arytenoid cartilages being fixed, as before, upon a pin, and bound together, so that the glottis remains open only to the extent of the vocal cords themselves, they are tied to the narrow board to which the larynx is fixed. The board is placed perpendicularly; a thread is attached to the angle of the thyroid cartilage immediately above the anterior extremity of the vocal cords, and is allowed to hang perpendicularly suspending a small scale with weights. As the amount of the weight in the scale is increased, the thyroid cartilage is depressed towards the cricoid, and the space occupied by the crico-thyroid membrane or ligament is narrowed, while the vocal cords are in the same degree stretched. We thus imitate the action of the crico-thyroid muscles. Those notes only were adopted as the basis of comparison which were produced by the most feeble blast. On account of the influence of the force of the blast on the pitch of the notes, it is impossible to determine quite accurately the note produced by a certain extending force; but I feel confident that the errors arising from this source cannot be so much as a semitone, since the lowest note produced by a given tension was always adopted. On the whole, such errors would balance each other; and indeed, the want of purity in the individual notes produced by the given weights did not seem great to the ear of a singer, who determined the pitch of each note by a pianoforte. The extraordinary height to which the notes were raised by tension of the cords, was the more remarkable from the larynx being that of a male subject.

Experiment 1.

Weights in loths.	Notes pro- duced.	
$\frac{1}{2}$	A $\sharp$,	
1	B	
$1\frac{1}{2}$	C	
2	C $\sharp$	
$2\frac{1}{2}$	D	
$2\frac{3}{10}$	D $\sharp$	
3	E	
$3\frac{1}{2}$	F	
4	F $\sharp$	
$4\frac{1}{2}$	G	
5	G $\sharp$	
$5\frac{1}{2}$	A	
6	A $\sharp$	
$6\frac{1}{2}$	B $\sharp$	
7	B $\sharp$ —C $\sharp$	
$7\frac{1}{2}$	C $\sharp$	
8	C $\sharp$ $\sharp$	
$8\frac{1}{2}$	D $\sharp$	
$9\frac{7}{10}$	D $\sharp$ $\sharp$	
$10\frac{7}{10}$	E $\sharp$	
$11\frac{7}{10}$	F $\sharp$	
13	F $\sharp$ $\sharp$	
15	G $\sharp$	
17	G $\sharp$ $\sharp$	
19	A $\sharp$	
22	A $\sharp$ $\sharp$	
25	B $\sharp$	
28	C $\sharp$	
31	C $\sharp$ $\sharp$	
35	D $\sharp$	
37	D $\sharp$ $\sharp$	

No further note produced

Experiment 2.

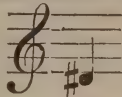
Weights in loths.	Notes pro- duced.	
$\frac{1}{2}$	B,	
1	C	
$1\frac{1}{2}$	C $\sharp$	
2	D	
$2\frac{1}{2}$	D $\sharp$	
3	E	
$3\frac{1}{2}$	F	
4	F $\sharp$	
$4\frac{1}{2}$	G	
5	G $\sharp$	
$5\frac{1}{2}$	A	
6	A $\sharp$	
$6\frac{1}{2}$	B $\sharp$	
$7\frac{1}{2}$	C $\sharp$	
$8\frac{3}{10}$	C $\sharp$ $\sharp$	
9	D $\sharp$	
10	D $\sharp$ $\sharp$	
11	E $\sharp$	
12	F $\sharp$	
13	F $\sharp$ $\sharp$	
15	G $\sharp$	
$17\frac{1}{2}$	G $\sharp$ $\sharp$	
18	A $\sharp$	
20	A $\sharp$ $\sharp$	
22	B $\sharp$	
26	C $\sharp$	
29	C $\sharp$ $\sharp$	
32	D $\sharp$	
37	D $\sharp$ $\sharp$	

No further note
produced.

After the completion of the first experiment, the vocal cords had only so far suffered, that with an extending force of half a loth they yielded the note B in place of A $\sharp$.

Bass notes produced by pressing the thyroid towards the arytenoid cartilages,
page 1012.

For the performance of these experiments, as described at page 1012, the presence of several persons is always necessary: one blows through the tube fixed to the larynx; another puts the weights upon the scale; and a third ascertains the value of the sounds produced by means of a pianoforte. In the experiment which I shall give

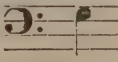
here as an example, the sound from which we started was D $\sharp$, ; the force applied to produce the relaxation of the cords being $\frac{3}{10}$ ths of a loth. In proportion as the relaxation of the cords was increased, the sounds fell in pitch as follows;

Notes produced—D $\sharp$, D, C $\sharp$, C, B, A $\sharp$, A, E, and G $\sharp$, E, D $\sharp$, D, C $\sharp$, B.

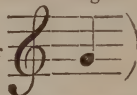
Weight in loths— $\frac{3}{10}$, $\frac{1}{2}$, 1, $1\frac{3}{10}$, $1\frac{4}{10}$, $1\frac{1}{2}$, $1\frac{7}{10}$, $2\frac{2}{10}$, $2\frac{4}{10}$, $2\frac{6}{10}$, $2\frac{8}{10}$, $3\frac{1}{10}$, $3\frac{3}{10}$.

Influence of the force of the blast on the pitch of the sounds; the tension of the vocal cords remaining the same, page 1014.

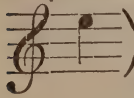
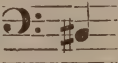
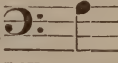
By blowing with gradually increased force while the weight by which the cords are extended remains the same, the sounds may be raised the extent of a “fifth” or more; the intervening semitones succeeding each other with facility. If, for example, G of

the first octave of the bass on the pianoforte  was the fundamental note of

the vocal cords produced by the feeblest possible blast, by a successive increase of the force of the current of air G, G $\sharp$, A, A $\sharp$, B, C, C $\sharp$, were obtained. If the tension of the vocal cords was now increased to such a degree that with the feeblest

blast they yielded the octave of the former G (or ), by blowing with gra-

dually increased force, the successive semitones up to the E above the last G (or

) were produced in considerable purity. In another experiment the successive semitones were produced from D $\sharp$  to A. .

This rise in pitch, effected by blowing with increasing force, was observed by Liscovius; Ferrein* also was aware of it, but estimated it too low, namely, at a semitone or tone.

The sounds obtained from dry tongues of caoutchouc also can be raised in pitch, though only the extent of a few semitones, by increasing the force of the blast; while from moist bands of arterial tissue, like the true vocal cords, a succession of semitones to the extent of a “fifth” above the fundamental note can be obtained by blowing with increasing force.

From these experiments it results that one and the same note (x) can be produced in the human larynx in two different ways; 1st, by a gentle current of air, when the vocal cords must have such length and tension (y) that their fundamental note is x ;

* Mém. de l'Acad. de Paris, 1741, p. 431.

and, secondly, by a more forcible current, when the length and tension of the cords is such that their fundamental note would belong to the octave below. The two sounds thus produced, though the same in pitch, are very different in quality. The first is much fuller in tone, the latter is harsh and shrieking, and has less fulness of tone the further distant the fundamental note, which the vocal cords would give with a feeble blast, is from the note *x* obtained by blowing thus forcibly. Even when the maximum of tension is attained at which the vocal cords will yield sounds to a feeble blast,—when the highest note which can be produced by mere tension of the cords is attained,—the sounds can still be raised a few tones, though with a shrieking character, by blowing more forcibly. We can experience this, indeed, in our own person; and we thus learn how much experiments on the larynx removed from the dead body tend to elucidate the phenomena of voice during life, and how nearly the latter can thus be imitated.

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